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THESIS

THE INFLUENCE OF FIN HEIGHT AND WALL CONDUCTIVITY ON INTEGRAL-FIN TUBES DURING STEAM CONDENSATION

by

David William Meyer

March, 1994

Thesis Advisor: Paul J. Marto

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The Influence of Fin Height and Wall Conductivity on Integral-Fin Tubes During Steam Condensation

by

David William Meyer
Lieutenant, United States Navy
B.S., The Ohio State University, 1987

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Author: David William Meyer
David William Meyer

Approved by: P. J. Marto
Paul J. Marto, Thesis Advisor

Ashok K. Das.
Ashok K. Das, Second Reader

Matthew Kelleher
Matthew D. Kelleher, Chairman
Department of Mechanical Engineering

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Heat transfer performance of horizontal, integral-fin tubes made of copper, aluminum, copper-nickel, and stainless steel was evaluated using a boiler and steam condenser assembly. Testing was done at vacuum and atmospheric pressure conditions. The tubes tested had an inner diameter of 12.7mm, a root diameter of 13.88mm, and fin heights ranging from 0.5mm to 1.5mm, in 0.25mm increments. The outside heat transfer coefficient was determined first by finding the overall heat transfer coefficient, U_o, then by using the Modified Wilson Plot Technique.

The results indicated that the performance of a finned tube is very dependent on fin height and tube material. Moreover, the results were compared with the predictive models of Beatty and Katz, Rose, Adamek and Webb, and Honda et al., with a modified version of the Rose model demonstrating the best predictive capabilities.

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NOMENCLATURE

A_{ef}	effective surface area as defined by eqn. (5), m^2
A_{fs}	surface area of fin flank as defined by eqn. (6), m^2
A_{ft}	surface area of fin tip as defined by eqn. (7), m^2
A_i	inside surface area of test tube, m^2
A_o	outside surface area of smooth tube m^2
$A_{tot,p}$	outside area of test tube for one pitch length, m^2
A_u	unfinned surface area as defined in eqn. (8), m^2
B_1	constant used by Rose [Ref. 4], equal to 2.96
B_f	constant used by Rose [Ref. 4], equal to 0.143
B_s	constant used by Rose [Ref. 4], equal to 0.143
B_t	constant used by Rose [Ref. 4], equal to 0.143
C_i	assumed leading coefficient for h_i as in eqn. (25)
c_p	specific heat at constant pressure, J/(kg K)
D_{eq}	equivalent diameter as defined in eqn. (3), m
D_i	inside diameter of test tube, m
D_o	outside diameter of test tube, or smooth tube, m
D_r	root diameter of finned tube, m
f_f	fraction of unflooded fin flank surface area that is covered with condensate
f_s	fraction of unflooded interfin surface area that is covered with condensate
g	gravitational constant, 9.81 m/s^2
h_{fg}	specific enthalpy of vaporization, J/kg
h_i	inside heat transfer coefficient, $W/(m^2\ K)$

h_o	outside heat transfer coefficient, $W/(m^2\ K)$
k	thermal conductivity, W/(m K)
k_{cw}	thermal conductivity of coolant, W/(m K)
k_f	thermal conductivity of condensate film, W/(m K)
K_1	constant as defined in eqn. (28)
K_2	constant as defined in eqn. (29)
L	length of test tube, m
$\bar{L}$	fin flank length as defined in eqn. (4), m
LMTD	log mean temperature difference, K
$\dot{m}$	mass flow rate of coolant, kg/s
n_f	number of fins per unit length of tube, m^{-1}
Pr	Prandtl number
q_f	fin flank heat flux as defined in eqn. (10), W/m^2
q_s	interfin heat flux as defined in eqn. (11), W/m^2
q_t	fin tip heat flux as defined in eqn. (12), W/m^2
Q	heat transfer rate as defined in eqn. (19), W
Re	Reynolds number
s	interfin spacing, m
t	fin thickness, m
T_1	coolant inlet temperature, K
T_2	coolant outlet temperature, K
T_f	film temperature, K, or constant as in eqn. (16)
T_s	steam temperature, K, or constant as in eqn. (17)
T_{sat}	steam saturation temperature, K
T_t	constant as defined in eqn. (15)
T_w	tube outside wall temperature (at fin base), K

U_o overall heat transfer coefficient, $W/(m^2\ K)$

GREEK SYMBOLS

α assumed leading coefficient to find h_o

ΔT temperature difference across the condensate film, K

η_f fin efficiency

ϵ constant as defined in eqn. (27)

$\epsilon_{\Delta T}$ enhancement ratio for a given temperature difference as defined in eqn. (14)

μ dynamic viscosity, kg/(m s)

μ_f condensate film dynamic viscosity, kg/(m s)

ρ density, kg/m^3

ρ_f condensate film density, kg/m^3

ρ_{fg} fluid/vapor density difference, kg/m^3

ρ_v vapor density, kg/m^3

ϕ condensate flooding angle as defined in eqn. (13)

σ condensate surface tension, N/m

$\xi(\phi)$ constant as used in eqn. (11)

Ω Petukhov-Popov function as defined in eqn. (26)

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I. INTRODUCTION

A. BACKGROUND

Today, all over the world, steam plants are being used to provide power and electricity on land, and to propel ships and submarines at sea. Because of this extensive use of steam plants in general, and condensers in particular, it becomes apparent that any enhancement in the performance of a condenser could be of enormous benefit. For example, electricity could be generated cheaper, fuel consumption could be reduced, or ship speeds could be increased for a given power plant.

One method of increasing condenser, and hence steam plant performance, is to use "enhanced" condenser tubes. These tubes offer an increase in performance by enhancing the heat transfer on either the inside or outside of the tubes. Therefore, using these tubes would allow for smaller, more efficient future condensers. Moreover, higher efficiency could be achieved for existing power plants by retubing with enhanced tubes.

One type of enhanced tube is the integral-fin tube. An integral-fin tube is a tube with circumferential fins on its outside, manufactured by machining the material between the fins away. As the fin material always was part of the original

tube stock, there is no contact resistance between the fin and the tube wall. (ie, The fin is an integral part of the tube.)

There are two main reasons why integral-fin tubes are enhanced over smooth tubes. One reason is because of the added surface area presented by the fins for heat transfer. The other reason is the interaction between the surface tension of the condensate and the fins themselves.

Increasing the surface area of a tube, one might surmise, would be very important in enhancing the heat transfer performance of a tube. After all, the more surface area there is, the more area there is for heat transfer. However, one would also surmise that there must be a limit to heat transfer enhancement. Particularly with lower conductivity materials, it is intuitively obvious that there is a fin height beyond which no further practical heat transfer increase will occur. This limit in heat transfer rate results from the competitive effects of increased condensing surface, and decreased heat conduction (fin efficiency) through the fin as fin height increases. The effect of fin efficiency during single phase heat transfer is well known in setting a proper integral fin height.

The interaction between the fins and the condensate during condensation is a complex one, with two competing effects arising from surface tension. One effect is to thin the condensate film on the upper part of the tube. This is called the unflooded region. On the lower part of the tube,

the presence of the fins causes condensate to be retained in the space between the fins. This is called the flooded region. These regions are shown in Figure 1.

The unflooded region demonstrates enhanced heat transfer. This is because the condensate film on the tube wall and fin flanks is kept very thin by the action of surface tension and gravity. As the condensate has a much lower thermal conductivity than the typical metal tube, its thinning increases the amount of heat transfer.

Again, because of the low conductivity of the condensate, the heat transfer is drastically reduced in the flooded portion of the tube. When compared to the unflooded portion, the amount of heat transfer provided by the flooded portion is very small.

Unfortunately, by increasing the fin height, the flooded portion of the tube is increased as well, again because of the effects of surface tension. This tends to reduce the amount of heat transfer, and competes directly with the enhancing factor of increased tube surface area mentioned earlier.

Much work has already been done with integral-fin tubes at the Naval Postgraduate School (NPS) and elsewhere. However, the vast majority of work has been done with copper tubes because of its high thermal conductivity and ease of fabrication. Because of strength and/or corrosion concerns,

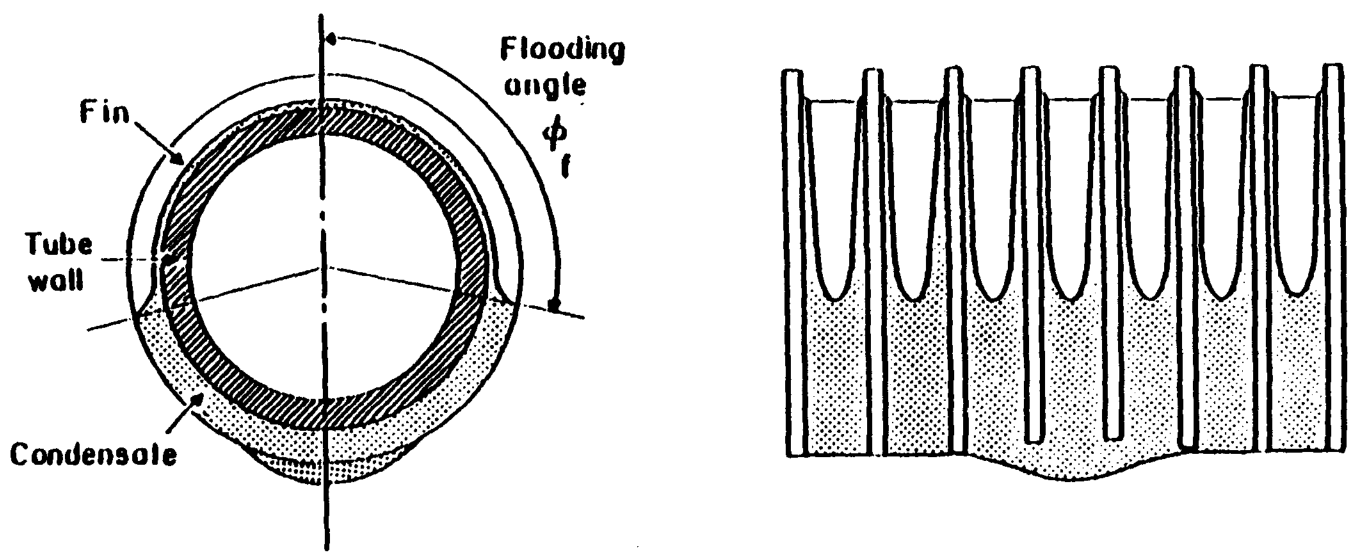


Figure 1 Schematic of Condensate Retention Angle on Finned Tubes and Condensate Wedge (illustrated by the gray sections)

most condensers use tubes made of copper-nickel, bronze, stainless steel, or titanium, all of which have much lower thermal conductivities than copper.

B. PREDICTIVE MODELS

It is obvious that enhanced tubes are advantageous. However, being able to predict their performance would be even more advantageous. After all, how does one design a condenser when the performance of the tubes isn't well known? For that matter, how does one tell if performance of enhanced tubes is worth the added cost of manufacturing them?

Nusselt [Ref. 1], in 1916, was the first to successfully predict the performance of smooth tubes. Since then, Beatty and Katz [Ref. 2], Adamek and Webb [Ref. 3], Rose [Ref. 4], and Honda et al. [Ref. 5] have all attempted to predict, with varying degrees of success, the performance of integral-fin tubes.

There is very little experimental validation of the previously mentioned integral-fin models and virtually all the data are with copper tubes (though Jaber and Webb [Ref. 6], have done some very recent work with other materials). Therefore, the previously mentioned models remain essentially unproven with regard to tubes that would be used in actual condensers.

C. NAVAL POSTGRADUATE SCHOOL CONDENSATION RESEARCH

This thesis is part of an ongoing research program to study enhanced condensation. Much work has been done over the years with integral-fin tubes of various dimensions, though most has been done only with copper tubes. Mitrou [Ref. 7], and most recently Cobb [Ref. 8], looked at tubes of different materials but with only limited variations of fin height.

D. OBJECTIVES

The main objectives of this thesis are as follows:

1. Obtain repeatable data for integral-fin tubes made of different materials, to study the effects of thermal conductivity on tube performance.

2. Compare data for tubes of the same material but different fin heights, to demonstrate the effect of fin height on tube performance.

3. Compare the experimental results with available predictive models, to validate the models.

II. A REVIEW OF RELEVANT PREDICTIVE MODELS

A. NUSSELT MODEL

As mentioned previously, Nusselt [Ref. 1] was the first to formulate an equation for the average heat transfer coefficient for a smooth horizontal tube during film condensation:

$$h_o = 0.728\left[\frac{k_f^3 g h_{fg} \rho_f (\rho_f - \rho_v)}{\mu_f D_o (T_{sat} - T_{wo})}\right]^{1/4} \tag{1}$$

In order to develop his equation, Nusselt assumed that the tube operates *in a quiescent vapor*, that is a vapor with zero velocity. While his model remains generally valid, in reality any vapor in a condenser will have some velocity. Assuming downward flow, the vapor velocity would tend to thin the condensate film and enhance the heat transfer above what the Nusselt model predicts.

B. BEATTY AND KATZ MODEL

In 1948, Beatty and Katz [Ref. 2] formulated an equation for the average heat transfer coefficient for integral-fin tubes. They took into account the thermal conductivity of the wall material in order to accurately model the effect of the fins. However, to simplify the problem they neglected the

effects of condensate surface tension. For rectangular shaped fins, their equation takes the form:

$$h_o=0.689\left[\frac{k_f^3\rho_f^2 g h_{fg}}{\mu_f D_{eq}(T_{sat}-T_{wo})}\right]^{1/4} \tag{2}$$

where

$$\left[\frac{1}{D_{eq}}\right]^{1/4}=1.3\eta_f\frac{A_{fs}}{A_{ef}\bar{L}^{1/4}}+\eta_f\frac{A_{ft}}{A_{ef}D_o^{1/4}}+\frac{A_u}{A_{ef}D_r^{1/4}} \tag{3}$$

and

$$\bar{L}=\pi\frac{(D_o^2-D_r^2)}{4D_o} \tag{4}$$

$$A_{ef}=n_fA_{fs}+n_fA_{ft}+A_u \tag{5}$$

$$A_{fs}=\frac{n_f\pi(D_o^2-D_r^2)}{2} \tag{6}$$

$$A_{ft}=n_f\pi D_o t \tag{7}$$

$$A_u=n_f\pi D_r s \tag{8}$$

As Beatty and Katz ignored surface tension, one would expect their model to perform better for low surface tension

fluids, such as refrigerants, than it would for water. Also, the model would predict the performance better under high pressures and hence, high saturation temperature conditions where surface tension would be lower.

C. ROSE MODEL

Rose [Ref. 4] in 1993, developed a simple but complete model for determining the outside heat transfer coefficient for integral-fin tubes. Unlike Beatty and Katz [Ref. 2], he took into account the effects of surface tension, gravity induced drainage from the tube, and condensate flooding. He did, however, choose to ignore the effects of fin efficiency as he primarily dwelled on copper tubes which have a very high fin efficiency. Rose's equation for the outside heat transfer coefficient for an integral-fin tube is:

$$h_o=\left[\pi D_o t q_t+\frac{\phi}{\pi}\left[\frac{(1-f_f)\,\pi\,(D_o^2-D_r^2)}{2}q_f+(1-f_s)\,\pi D_r s q_s\right]\right]\frac{1}{\Delta T A_{tot,p}} \qquad (9)$$

where q_f, q_s, and q_t are the heat fluxes from the fin flanks, interfin space, and fin tips:

$$q_f=\left[\frac{\rho h_{fg} k^3 \Delta T^3}{\mu}\left[\frac{0.943^4 \rho_{fg} g}{h_v}+B_f\frac{\sigma}{h^3}\right]\right]^{1/4} \qquad (10)$$

$$q_s=\left[\frac{\rho h_{fg}k^3\Delta T^3}{\mu}\left[\frac{(\xi(\phi))^3\rho_{fg}g}{D_r}+B_s\frac{\sigma}{s^3}\right]\right]^{1/4} \tag{11}$$

and:

$$q_t=\left[\frac{\rho h_{fg}k^3\Delta T^3}{\mu}\left[\frac{0.724\rho_{fg}g}{D_o}+B_t\frac{\sigma}{t^3}\right]\right]^{1/4} \tag{12}$$

and the condensate flooding angle ϕ is:

$$\phi=\cos^{-1}\left[\frac{4\sigma}{\rho g s D_o}-1\right] \tag{13}$$

The quantities f_s and f_f represent the fraction of the unflooded portion of the interfin space and the fin flanks that are flooded with condensate.

Moreover, Rose defines the enhancement ratio $\epsilon_{\Delta T}$ as the ratio of the predicted outside heat transfer coefficient for a finned tube to that predicted by Nusselt at the same film temperature difference. This ratio is given as:

$$\epsilon_{\Delta T}=\frac{D_o t}{D_r(s+t)}T_t+\frac{\phi}{\pi}(1-f_f)\left[\frac{D_o^2-D_r^2)}{2D_r(s+t)}\right]T_f+\frac{\phi}{\pi}(1-f_s)B_1\frac{s}{(s+t)}T_s \tag{14}$$

where:

$$T_t=\left[\frac{D_r}{D_o}+B_t\frac{\sigma D_r}{0.728^4\rho_{fg}g t^3}\right]^{1/4} \tag{15}$$

$$T_t=\left[\left[\frac{0.943}{0.728}\right]^4\frac{D_r}{h_v}+B_t\frac{\sigma D_r}{0.728^4\rho_{fg}gh^3}\right]^{1/4} \tag{16}$$

and:

$$T_s=\left[\frac{(\xi(\phi))^3}{0.728^4}+B_s\frac{\sigma D_r}{0.728^4\rho_{fg}gs^3}\right]^{1/4} \tag{17}$$

Note that these equations contain four unknown coefficients, B1, Bs, Bf, and Bt. Rose curve fitted these equations to existing experimental data for copper tubes at atmospheric pressure (only) and determined that B1 should be 2.96, while Bf, Bs, and Bt, were all equal to 0.143.

Cobb [Ref. 8], in 1993 modified the Rose model to include the effects of fin efficiency. The modified Rose model therefore takes the form of:

$$h_o=\left[\pi D_o t q_t \eta_t+\frac{\Phi}{\pi}\left[\frac{(1-f_f)\pi(D_o^2-D_r^2)}{2}q_f\eta_f+(1-f_s)\pi D_r s q_s\right]\right]\frac{1}{A_{tot,p}} \tag{18}$$

D. ADAMEK AND WEBB MODEL

Adamek and Webb [Ref. 3] use a far different approach to determine the outside heat transfer coefficient. Like Rose [Ref. 4], gravity drainage, surface tension and the flooding angle are all taken into account. However, that is where the similarity ends.

Adamek and Webb chose not to ignore the effects of fin efficiency. Furthermore they decided to look at a length of tube which stretches from the midpoint at the tip of a fin to the midpoint of its adjacent interfin space (see Figure 2). The surface between those two points is then broken up into eight discrete segments, namely, ba, a0, 01, 12, 23, 34, 45, and 56. For each of these segments, a local condensation rate for the condensate surface is calculated. These condensation rates are then summed for both the flooded and unflooded portions of the tube. In addition, condensate film thicknesses are determined for each of the eight segments. The outside heat transfer coefficient is then a function of the condensation rates, film thickness, fin efficiency, temperature difference, and enthalpy. A major disadvantage of this model is its complexity compared to the models of Rose [Ref. 4] or Beatty and Katz [Ref. 2], and a numerical solution is required to solve the problem.

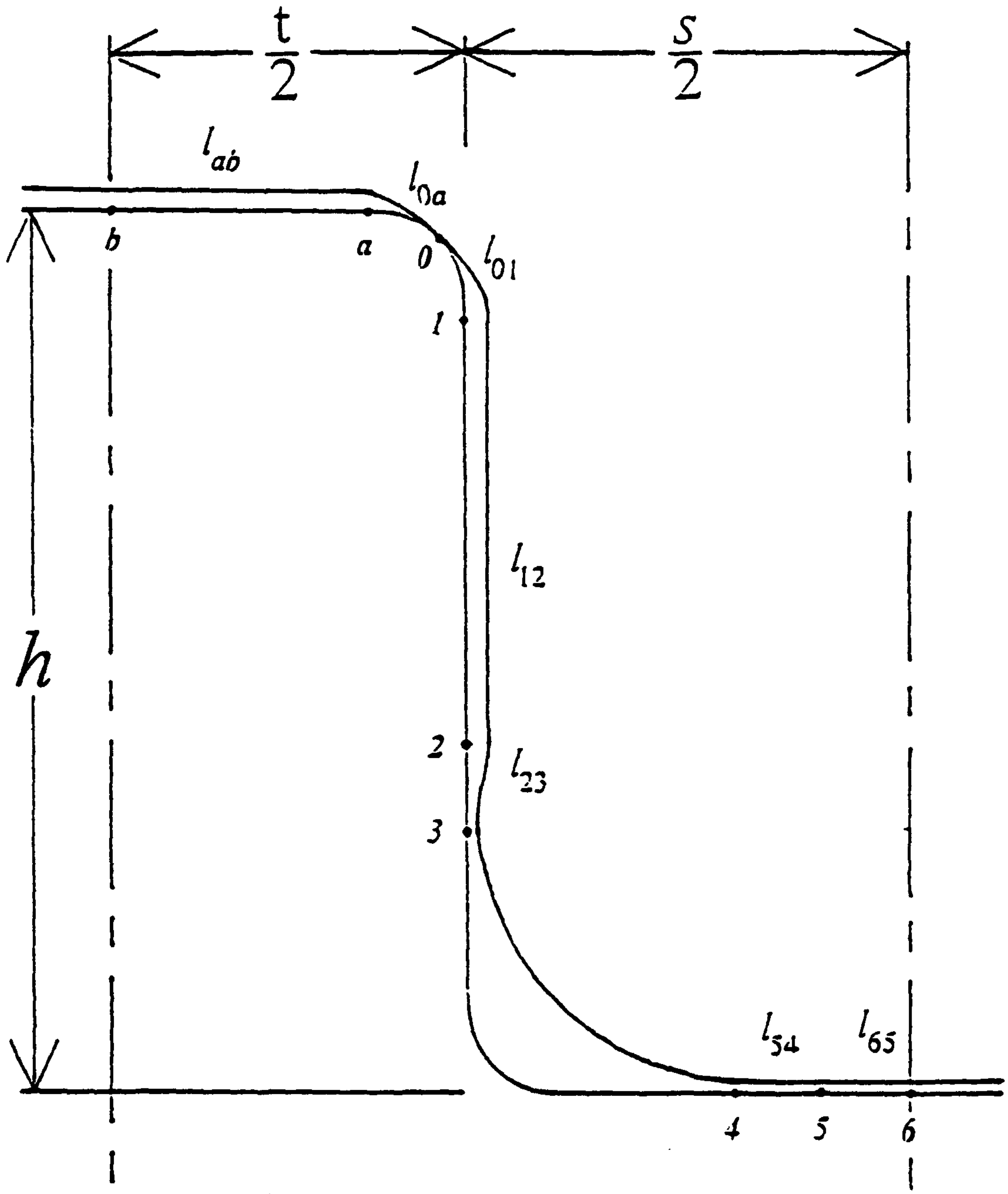
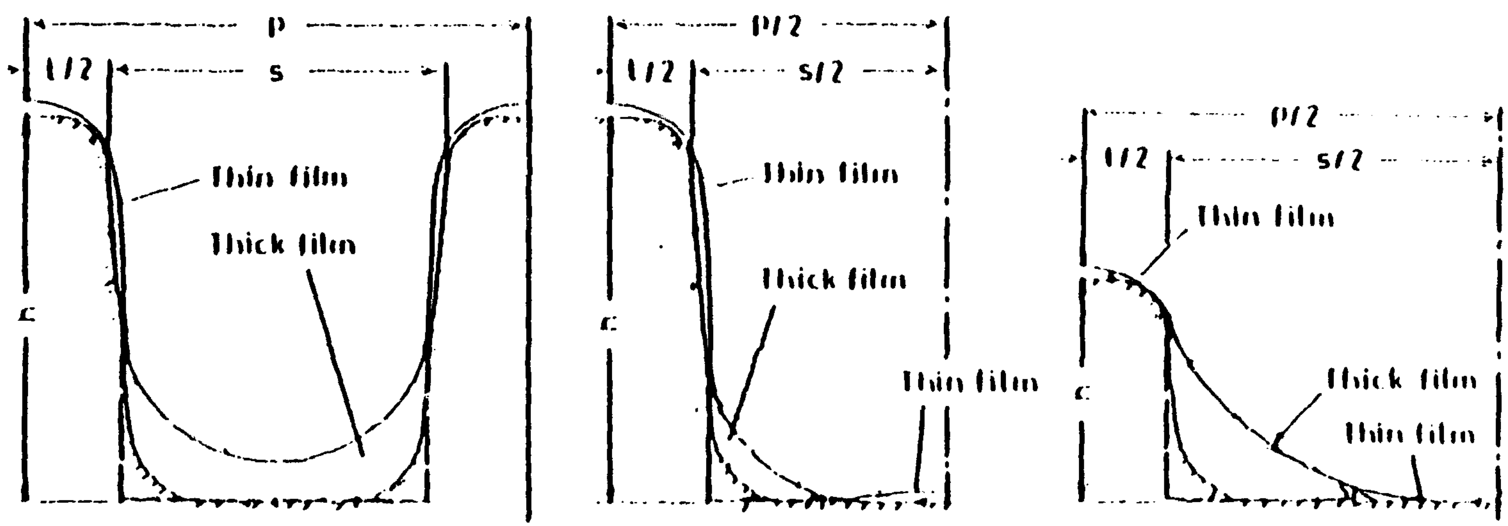


Figure 2 Half Fin/Interfin Space as Analyzed by Adamek and Webb

E. HONDA MODEL

The Honda et al. model [Ref. 5], like that of Adamek and Webb is quite complex, but is the most comprehensive model available. Like Adamek and Webb [Ref. 3], the condensate film thickness is calculated, and gravity and surface tension effects are considered. For Honda's model, three cases are considered based on fin spacing and condensation rate (see Figure 3 from Ref. 5). Different sub-models are used for each case. These cases are a function of fin spacing and condensation rate and are used because it is expected that the depth of the condensate film in the inter-fin space would have a significant impact on the amount of heat transferred.

Honda et al. [Ref. 5], however, take into consideration the properties of the test tube coolant, the inside heat transfer coefficient, and the tube wall conductivity in analyzing the heat transfer from the vapor to the coolant, and then determine the temperature field in the tube and fins. Therefore, their predicted outside heat transfer coefficient is a function of coolant properties, inside heat transfer coefficient, tube wall conductivity, fin efficiency, film thickness, and surface tension and temperature difference. This comprehensive analysis, however, requires a numerical solution.



Case A　　　　Case B　　　　Case C

Figure 3　Three Sub-Cases of the Honda et al. Model

III. EXPERIMENTAL APPARATUS

A. SYSTEM AND SYSTEM INSTRUMENTATION OVERVIEW

The system apparatus and instrumentation are identical to that as described by Cobb [Ref. 8]. A major computer upgrade is in progress, but has not yet been installed.

B. TUBES TESTED

As mentioned in the introduction, little experimental work has been done with tubes made of materials other than copper. For this work, tubes made of copper, aluminum, 90/10 copper-nickel, and 316 stainless steel were used in order to determine the relationship between tube heat transfer performance and tube thermal conductivity. The thermal conductivities for the tubes used were curve-fitted by Cobb [Ref. 8] for the temperature range of this work, from data taken from [Ref. 9]. Table I lists the thermal conductivities.

TABLE I. THERMAL CONDUCTIVITIES OF TUBE MATERIALS

MATERIAL	THERMAL CONDUCTIVITY (w/(m K))
COPPER	390.8
ALUMINUM	231.8
COPPER-NICKEL	55.3

	THERMAL CONDUCTIVITY (w/(m K))
STAINLESS STEEL	14.3

All tubes tested contained a heatex insert. The heatex insert is an insert of wire loops and is used to promote repeatable, consistent, turbulent flow on the inside of the tubes to enhance the inside heat transfer coefficient and lower the inside thermal resistance. The tubes tested, and their dimensions are listed in Table II.

TABLE II. SPECIFICATIONS FOR TUBES TESTED

TUBE MATERIAL	ROOT DIA. (MM)	FIN HEIGHT (MM)	OUTER DIA. (MM)	FIN THICKNESS (MM)	FIN SPACING (MM)
COPPER	13.88	1.50	16.88	1.00	1.50
COPPER	13.88	1.25	16.38	1.00	1.50
COPPER	13.88	1.00	15.88	1.00	1.50
COPPER	13.88	0.75	15.38	1.00	1.50
COPPER	13.88	0.50	14.88	1.00	1.50
COPPER	13.88	SMOOTH	13.88	---------	---------

TUBE MATERIAL	ROOT DIA. (MM)	FIN HEIGHT (MM)	OUTER DIA. (MM)	FIN THICKNESS (MM)	FIN SPACING (MM)
ALUMINUM	13.88	1.50	16.88	1.00	1.50
ALUMINUM	13.88	1.25	16.38	1.00	1.50
ALUMINUM	13.88	1.00	15.88	1.00	1.50
ALUMINUM	13.88	0.75	15.38	1.00	1.50
ALUMINUM	13.88	0.50	14.88	1.00	1.50
ALUMINUM	13.88	SMOOTH	13.88	---------	---------
COPPER-NICKEL	13.88	1.50	16.88	1.00	1.50
COPPER-NICKEL	13.88	1.00	15.88	1.00	1.50
COPPER-NICKEL	13.88	0.75	15.38	1.00	1.50
COPPER-NICKEL	13.88	0.50	14.38	1.00	1.50
STAINLESS STEEL	13.88	1.50	16.88	1.00	1.50
STAINLESS STEEL	13.88	1.25	16.38	1.00	1.50

TUBE MATERIAL	ROOT DIA. (MM)	FIN HEIGHT (MM)	OUTER DIA. (MM)	FIN THICKNESS (MM)	FIN SPACING (MM)
STAINLESS STEEL	13.88	1.00	15.38	1.00	1.50
STAINLESS STEEL	13.88	0.75	14.88	1.00	1.50
STAINLESS STEEL	13.88	0.50	14.38	1.00	1.50

IV. EXPERIMENTAL PROCEDURES AND DATA ANALYSIS

A. SYSTEM OPERATION AND TUBE PREPARATION

System (see Figure 4) operation was identical to that given by Cobb [Ref. 8]. For both atmospheric and vacuum runs, non-condensable gasses were removed by use of a vacuum pump. Simultaneously, the boiler heaters were turned on, and flow was initiated in the test tube. Once steady conditions were reached for the vacuum (saturation temperature of 48.7 degrees C) or atmospheric (saturation temperature of 100.0 degrees C) runs, cooling water flow was adjusted to 80% in the test tube.

At this point data collection commenced. The data collection procedure was repeated and the temperatures checked for consistency before saving them. If the data were sufficiently consistent, (+/- 1%) the flow through the test tube was repeated with the flow meter reduced to 70%. This process continued down to 20% flow in the test tube and was then repeated from 20% back up to 80%.

Tube preparation was also identical to that given by Cobb [Ref. 8] with the following exception:

- For aluminum tubes only, the treatment was stopped once a continuous oxide layer has been formed on the surface of the tube, but before dimensional changes had occurred because of excessive corrosion due to the high reactivity of aluminum.

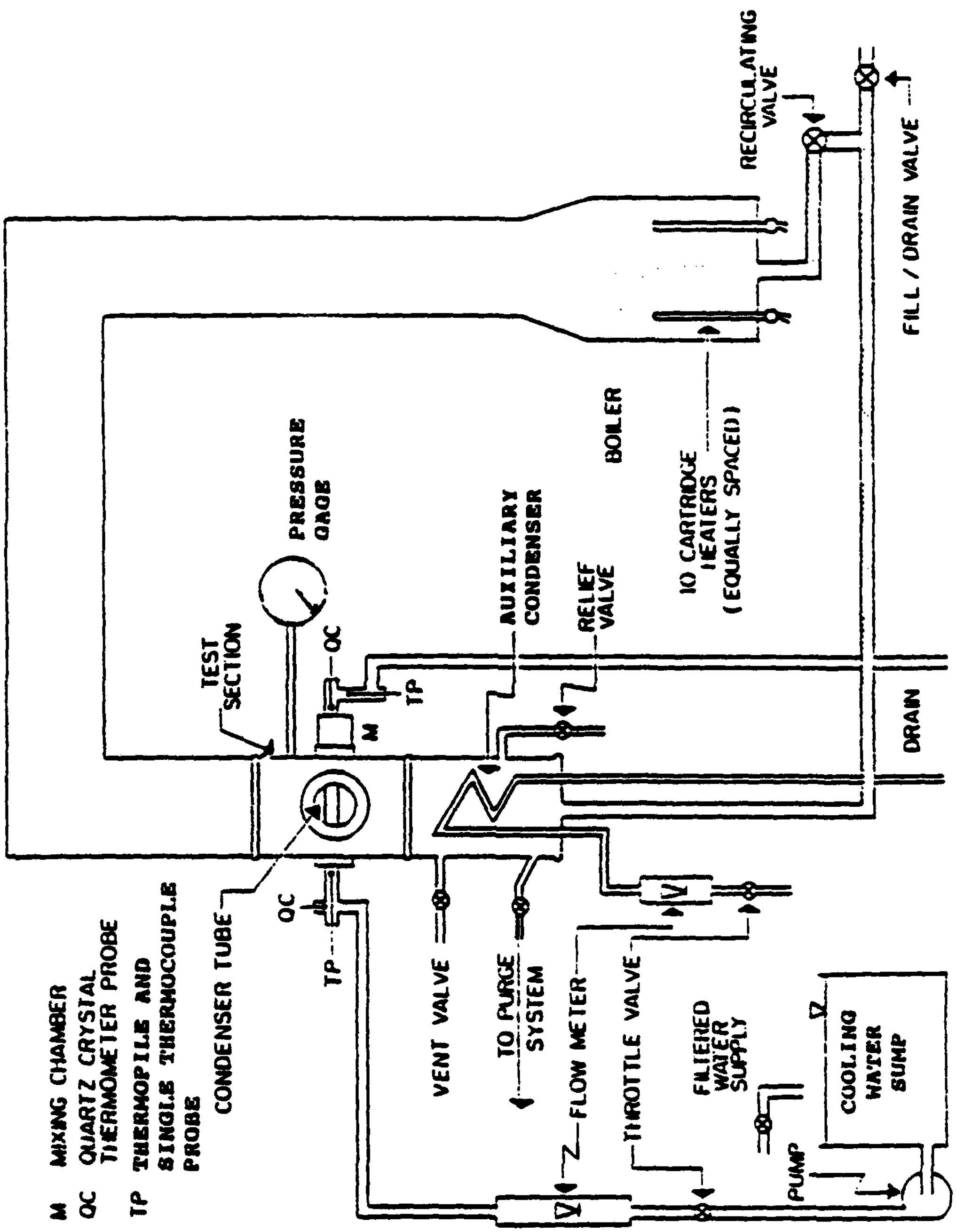


Figure 4 Schematic of the Single Tube Test Apparatus

B. COMPUTER CODES

Three different computer codes were used for analysis in this work. The first of these codes was used to take the raw data and do initial processing, while the second and third were codified versions of the previously mentioned predictive models.

1. DRPALL

"DRPALL" is the name of the data acquisition and initial processing program. It is an HPBASIC program and remains unchanged from that described by Cobb [Ref. 8]. When used, the DRPALL program asks the user for information regarding test tube material type and configuration. Once the operator is ready to commence data taking, DRPALL either measures directly via an HP 3497 Data Acquisition Unit, or prompts the operator for data regarding boiler voltage, steam temperature and pressure, coolant flow, and coolant differential temperature.

From this data the heat transfer rate can be calculated.

$$Q=\dot{m}C_p(T_2-T_1) \tag{19}$$

Then the overall heat transfer coefficient is calculated:

$$U_o=\frac{Q}{A_o(LMTD)} \tag{20}$$

where:

$$LMTD=\frac{T_2-T_1}{\ln\left[\frac{T_{sat}-T_1}{T_{sat}-T_2}\right]} \qquad (21)$$

Since the desired output is outside heat transfer coefficient, the principle of thermal resistances in series is used, where the tube wall thermal resistance is written as:

$$R_w=\frac{\ln\left[\frac{D_o}{D_i}\right]}{2\pi Lk} \qquad (22)$$

and the overall thermal resistance is given by:

$$\frac{1}{U_oA_o}=\frac{1}{h_iA_i}+R_w+\frac{1}{h_oA_o} \qquad (23)$$

DRPALL contains a computer code for the Modified Wilson Plot Technique to determine the inside and outside heat transfer coefficients. As described by Cobb [Ref. 8], the Modified Wilson Plot Technique uses the overall heat transfer coefficient to find the inside and outside heat transfer coefficients using assumed forms for them and following an iterative technique. Since the data were taken using the Petukhov-Popov correlation on the cooling water side[Ref. 10], the heat transfer coefficients were assumed to be:

$$h_o=\alpha\left[\frac{k_f^3\rho^2{}_f g h_{fg}}{\mu_f D_r \Delta T_f}\right]^{1/4} \tag{24}$$

$$h_i=C_i\left[\frac{k_{cw}}{D_i}\right]\Omega \tag{25}$$

where:

$$\Omega=\left[\frac{\frac{\epsilon}{8}RePr}{K_1+K_2\left(\frac{\epsilon}{8}\right)^{1/2}(Pr^{2/3}-1)}\right] \tag{26}$$

$$\epsilon=[1.82\log(Re)-1.64]^{1/2} \tag{27}$$

$$K_1=1+3.4\epsilon \tag{28}$$

and:

$$K_2=11.7+1.8Pr^{-1/3} \tag{29}$$

The values of α and C_i are calculated in the code. In addition, DRPALL contains corrections to take into account frictional heating of the coolant, as well as the fin effects of the two mounted ends of the test tube. More information for the Program DRPALL is given in Appendix A.

2. HEATMEYER

"HEATMEYER" is a computer code originally written by Cobb [Ref. 8] and called HEATCOBB. HEATMEYER is a slightly altered version of HEATCOBB in order to allow an interactive input of tube parameters. This program is written in FORTRAN and is a codified version of the Rose model [Ref. 4], with one very important difference. Cobb [Ref. 8] modified the Rose model to take into account the effects of fin efficiency. The same fin efficiency equation used by the Beatty and Katz model [Ref. 2], was applied.

All numerical values of outside heat transfer coefficient and enhancement, presented in this paper, that are attributed to Rose (modified) are determined by using this program. More information for the program *HEATMEYER* is given in Appendix B.

3. Tsujimori

In 1993, Tsujimori [Ref. 11], produced computer codes which calculate outside heat transfer coefficients and enhancements (for a given temperature difference) for the models of Nusselt, Beatty and Katz, Adamek and Webb, and Honda et al. All numerical values of outside heat transfer coefficient and enhancement presented in this thesis, which are attributed to Nusselt, Beatty and Katz, or Adamek and Webb, or Honda et al., were determined by use of Tsujimori's codes. More information regarding the Tsujimori programs is given in Appendix C.

V. RESULTS AND DISCUSSION

A. GENERAL DISCUSSION

Data were taken as described in Chapter IV, with two runs being done on each tube: one at atmospheric pressure, and another under vacuum conditions. Short form printouts of the data as taken and processed by program DRPALL are included in Appendix D.

The names of the data files give information on the tube type and configuration, as well as the type of operation. The first two letters of the file name tell which type of tube material was used. For example, "ss" means stainless steel, and "cn" means copper-nickel. The numerical values in the file name represent the fin height of the tube where "15" means a fin height of 1.5mm, "125" means 1.25mm, "1" means 1mm etc.,. Finally, if the file name ends with an "A", that means the experimental data were taken at atmospheric pressure, vice a vacuum. Any file that ends with an "R" means that an original run had been terminated because of equipment problems, and that the run had been repeated.

Any time experimental data are taken, experimental uncertainty becomes an important concern. Appendix E contains the program used to predict the uncertainty for any given run, as well as a brief explanation of the logic used. Appendix E

also contains the uncertainty analyses for all of the data runs.

Related to uncertainty is the issue of repeatability. Consistency of experimental results is very important. In other words, it is vital that the data taken reflect the way tubes transfer heat, not the way the author collected his data. To demonstrate repeatability, Table III is a comparison of data taken by Cobb [Ref. 8] and the author for two tubes of identical dimensions (1mm fin height, 1mm fin thickness, and 1.5mm fin spacing) at vacuum.

Another indication of repeatability is how the data from one tube compares with that of another, ie, are there any trends or does the data seem entirely random? As demonstrated in the plots to follow, there are some very clear trend which help establish the repeatability of any one individual data run.

TABLE III. COMPARISON OF INDEPENDENT RUNS OF FINNED TUBES

TUBE MATERIAL	Ci	alpha	ENHANCEMENT (delta T)
copper-nickel (Cobb)	2.33	1.07	1.32

copper-nickel (Meyer)	2.68	1.06	1.30
% difference	13.1	1.5	1.5
copper (Cobb)	2.99	1.50	1.85
copper (Meyer)	2.87	1.51	1.86
% difference	3.9	0.5	0.5

B. HEAT TRANSFER COEFFICIENT VS. TEMPERATURE DIFFERENCE

Figures 5 through 12 are plots of the outside heat transfer coefficient versus film temperature difference where the temperature difference, again, is defined as the difference between the saturation temperature of the steam and the outside wall temperature of the test tube calculated at the base of the fin. Figure 5 also shows some sample uncertaint bars as determined in Appendix E. Two points immediately make themselves clear:

1. Improvement of Enhanced Over Smooth Tube Performance

For two tube materials, copper and aluminum, data were taken on smooth tubes with the same outside diameter as the

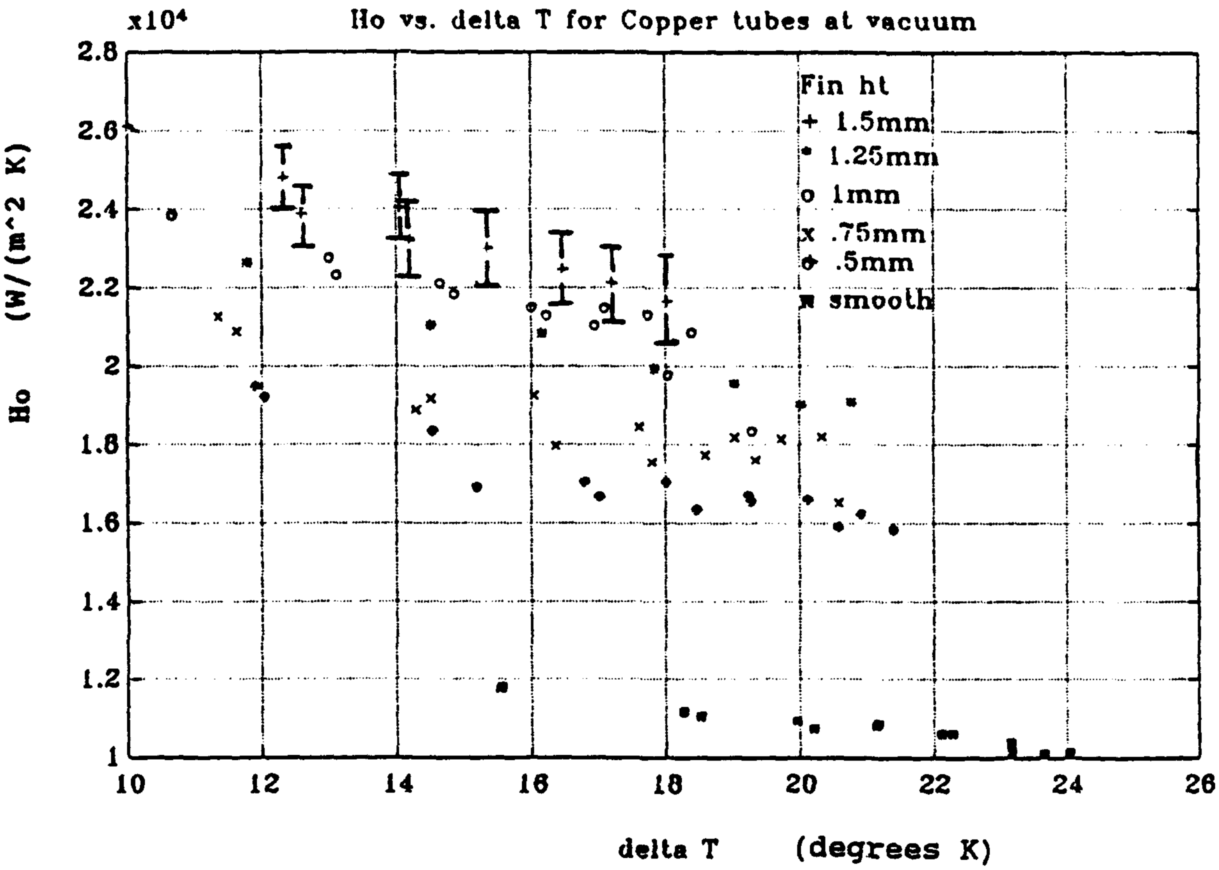


Figure 5 Experimental Results of Ho Vs. Temperature Difference for Copper Tubes at Vacuum

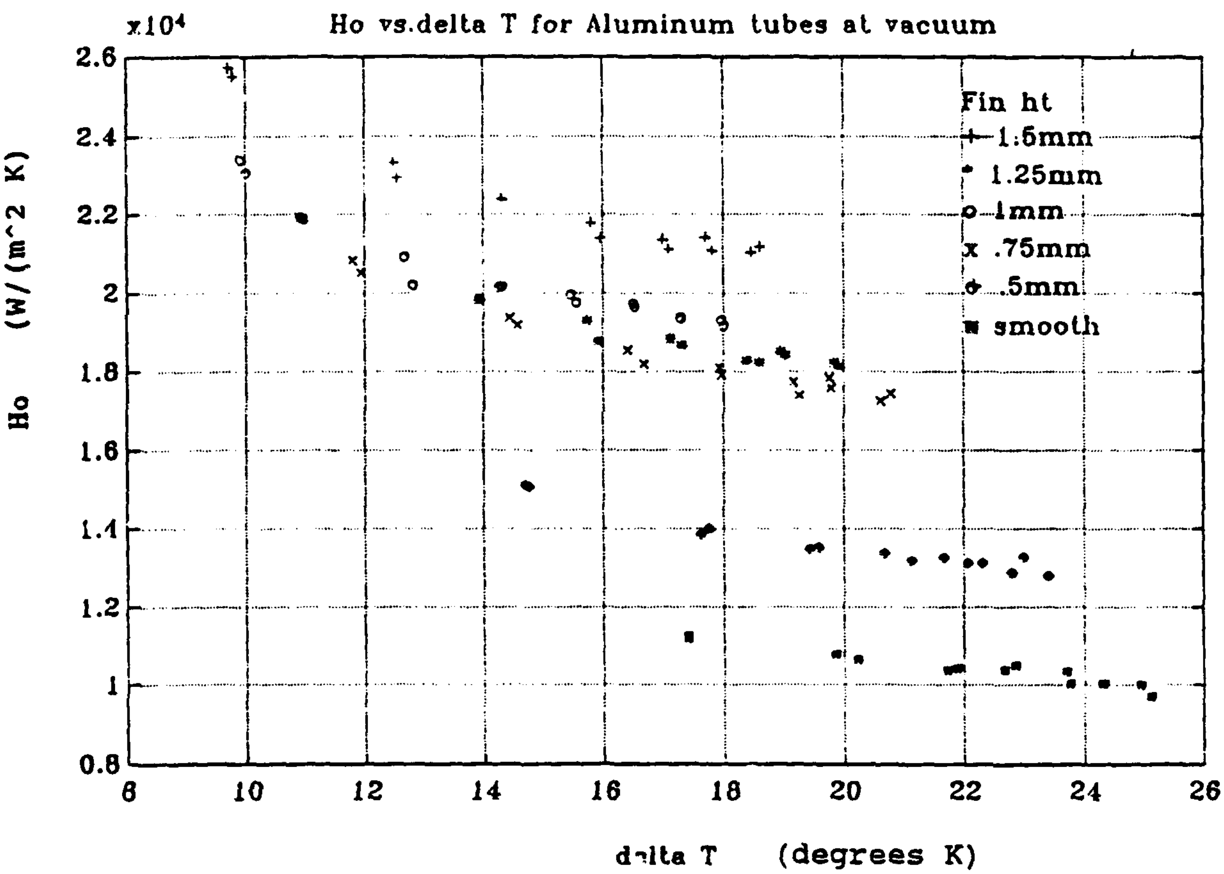


Figure 6 Experimental Results of Ho Vs. Temperature Difference for Aluminum Tubes at Vacuum

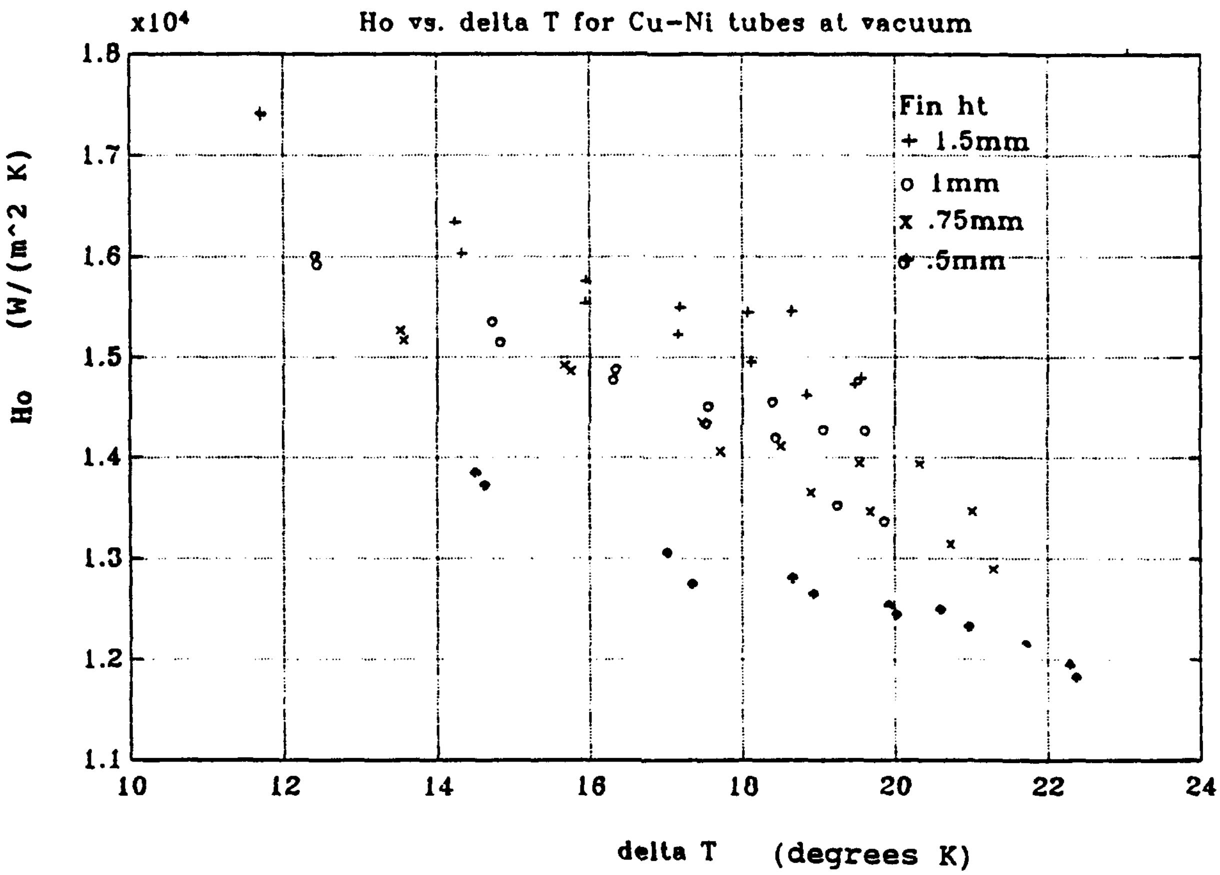


Figure 7 Experimental Results of Ho Vs. Temperature Difference for Copper-Nickel Tubes at Vacuum

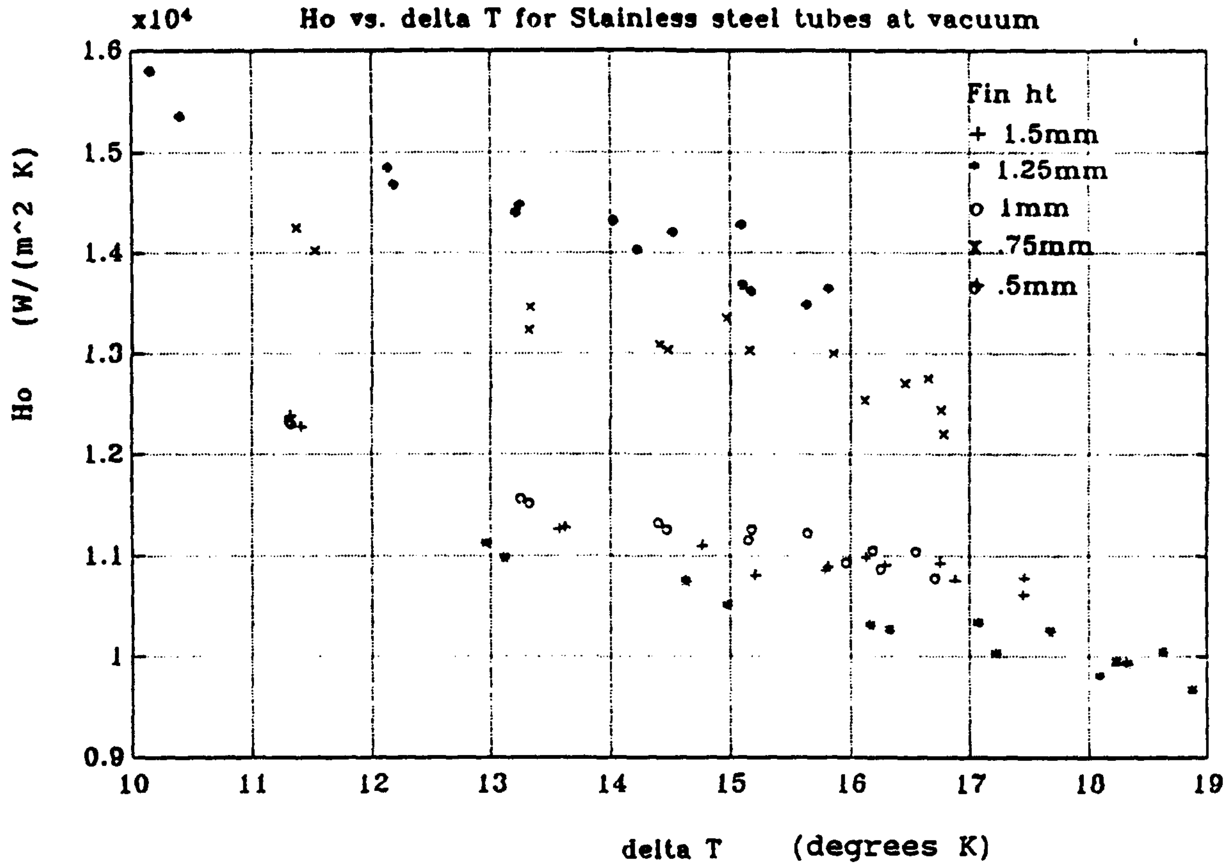


Figure 8 Experimental Results of Ho Vs. Temperature Difference for Stainless Steel Tubes at Vacuum

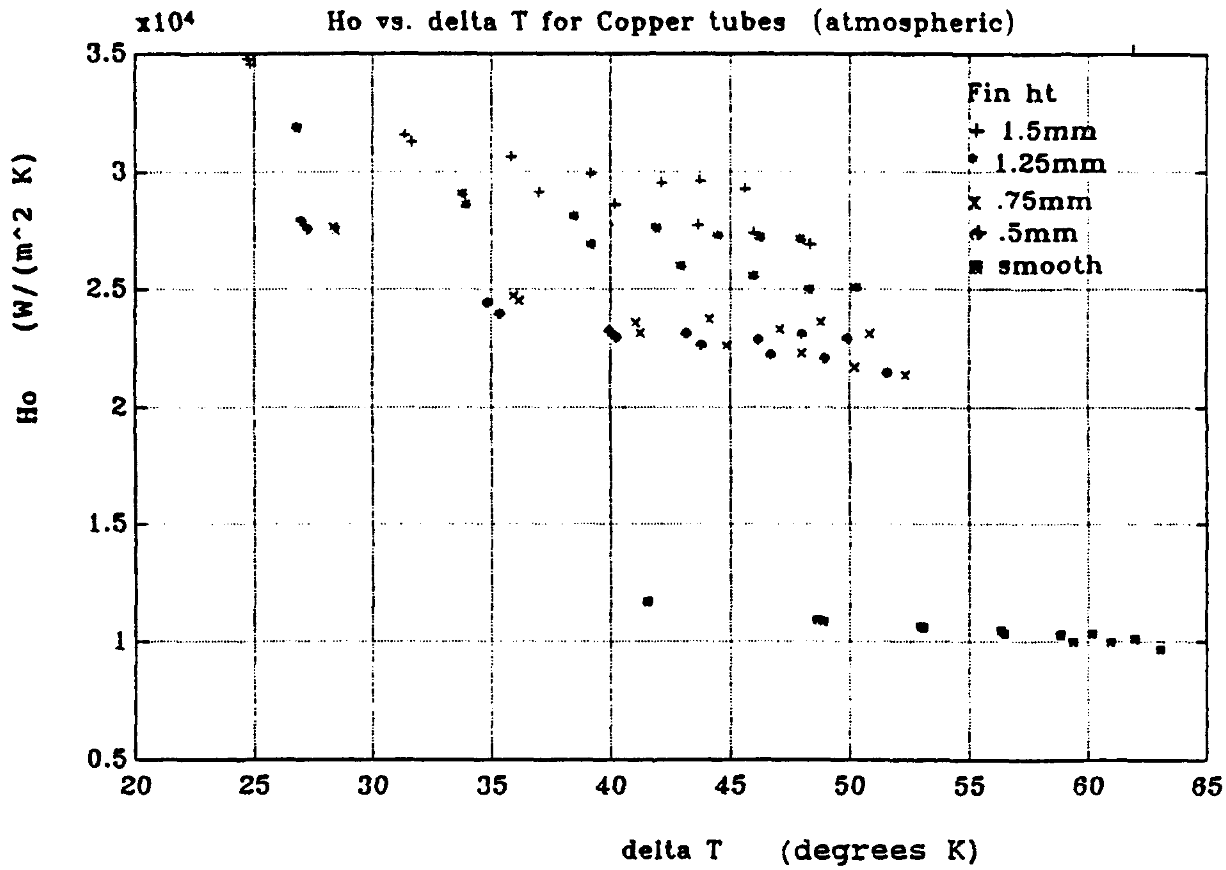


Figure 9 Experimental Results of Ho Vs. Temperature Difference for Copper Tubes at Atmospheric Pressure

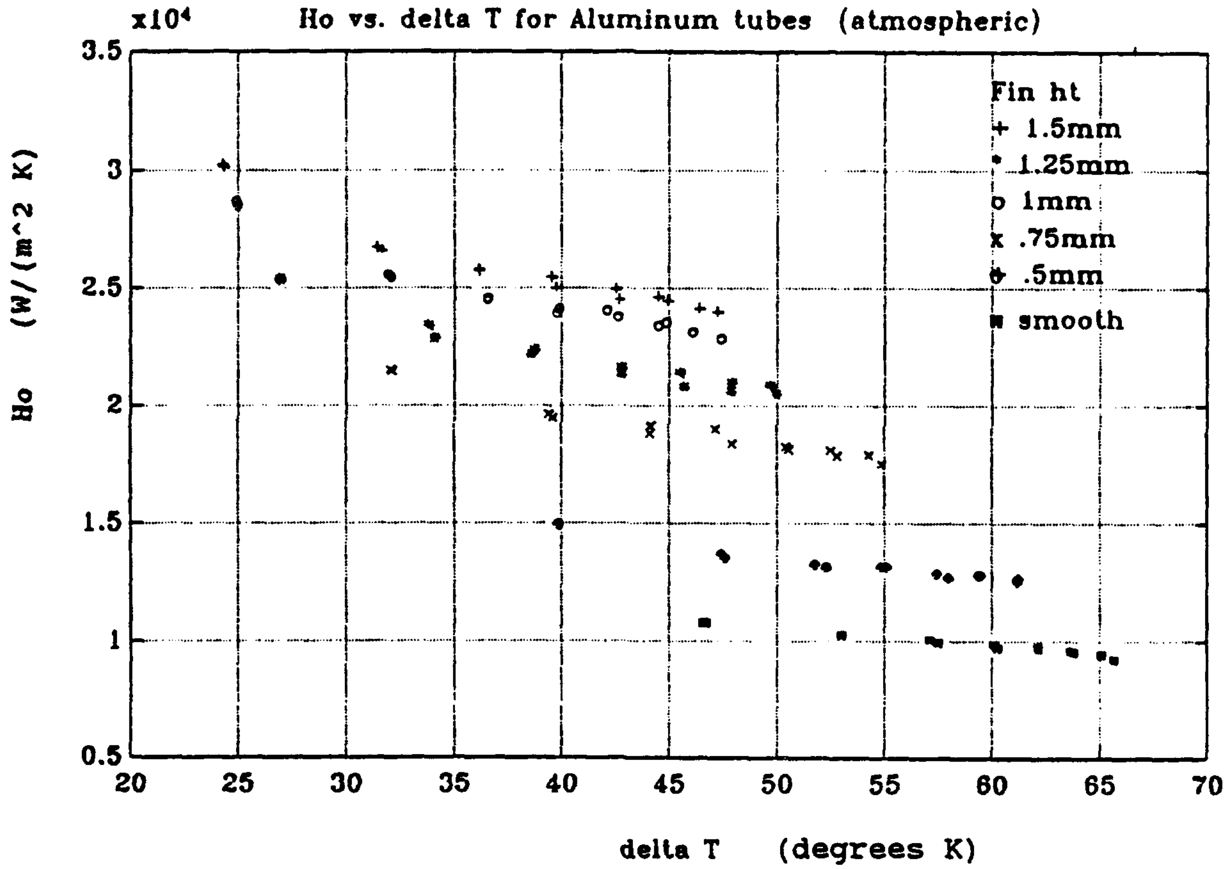


Figure 10 Experimental Results of Ho Vs. Temperature Difference for Aluminum Tubes at Atmospheric Pressure

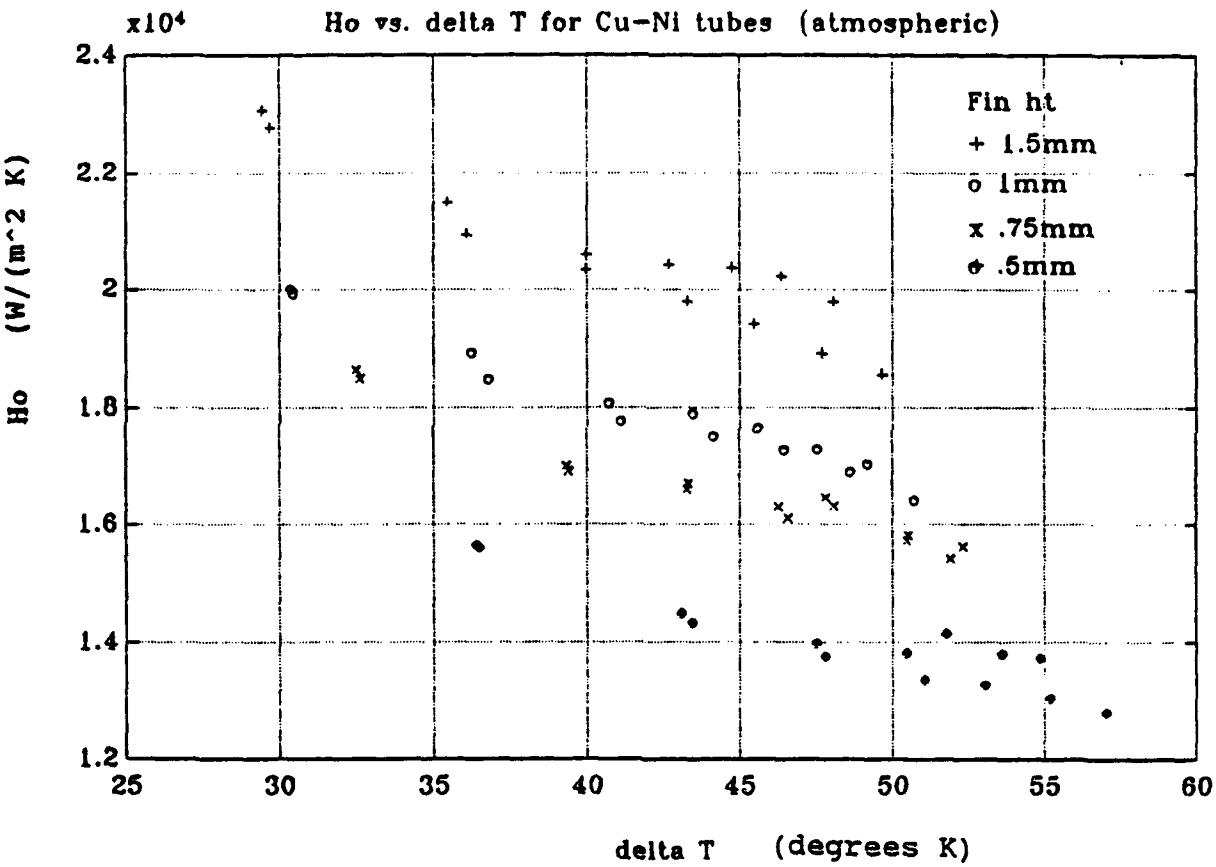


Figure 11 Experimental Results of Ho Vs. Temperature Difference for Copper-Nickel Tubes at Atmospheric Pressure

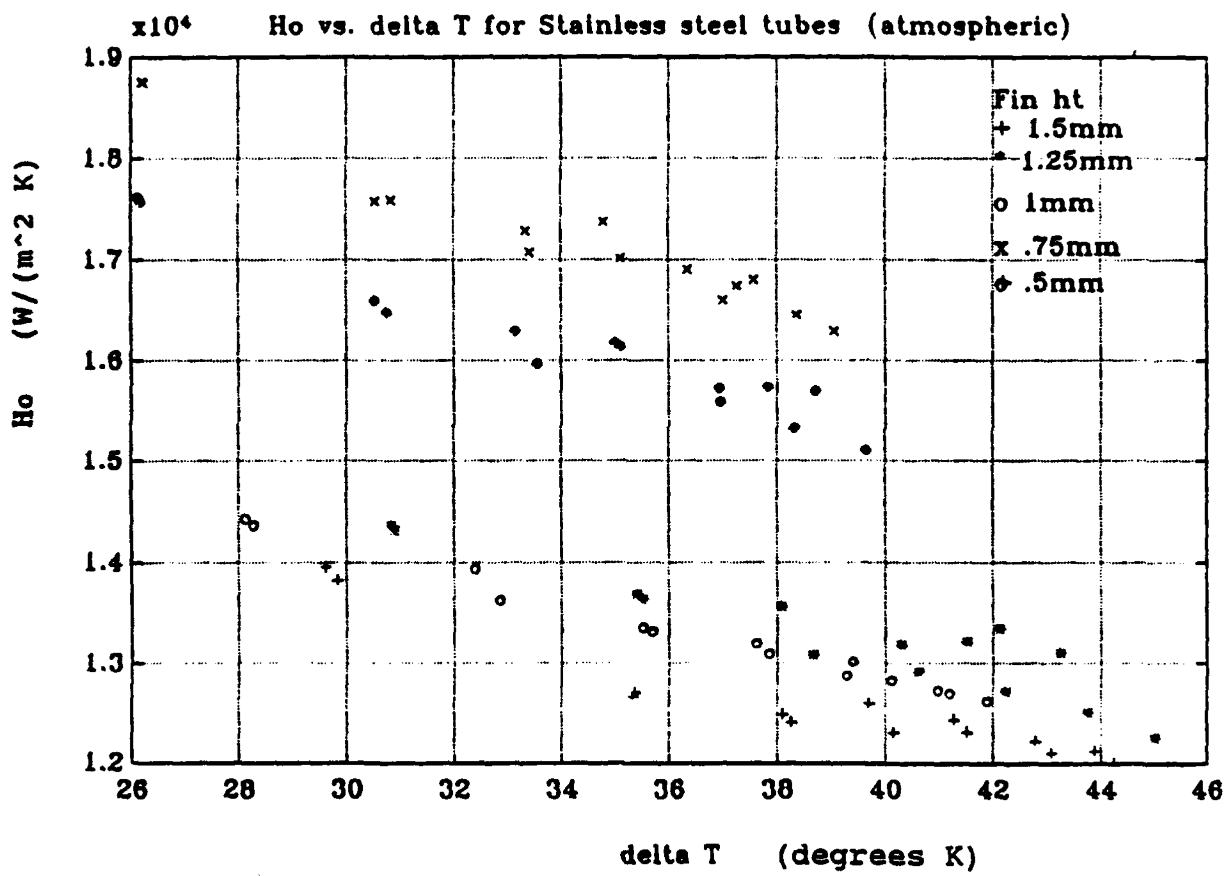


Figure 12 Experimental Results of Ho Vs. Temperature Difference for Stainless Steel Tubes at Atmospheric Pressure

diameter of the finned tubes at the base of the fins (ie the root diameter). Exactly as one would expect, there is a marked increase in the heat transfer of the integral-fin tubes when compared to the smooth tubes. These effects can be seen [illegible]

Impact of Conductivity on Tube Performance

When comparing the data for high conductivity materials, such as copper or aluminum, against the performance of low conductivity materials, such as copper-nickel or stainless steel, it becomes apparent that the conductivity of the material plays a large role in tube performance. There is a very definite trend established that as thermal conductivity decreases, so does heat transfer performance. The stainless steel plots in particular, (Figures 8 and 12) demonstrate that beyond fin heights of 0.5mm for vacuum, and 0.75mm for atmospheric, the effect of the low conductivity is so significant (ie, low fin efficiency) that the heat transfer coefficient does not increase with fin height.

In fact, beyond these critical fin heights, the heat transfer coefficient decreases with fin height. This can be explained by the fact that, as described previously in Chapter I, as fin height increases, not only is fin efficiency reduced, but, the amount of tube surface for effective condensation to occur, and therefore decreasing the outside heat transfer coefficient.

C. COMPARISON OF DATA WITH PREDICTIVE MODELS

Figures 13 through 20 are plots of outside heat transfer coefficient against temperature difference for the experimental data and five predictive models. This is done for tubes of a fin height of 0.75mm. The models are those of Adamek and Webb [Ref. 3], Honda et al. [Ref. 5], Beatty and Ka.. [Ref. 2], modified Rose [Ref. 4], and Nusselt [Ref. 1].

The Nusselt model is for a smooth tube vice a finned tube and is only included to provide an indication of the enhancement achieved by using finned tubing.

There are two models which seem to consistently predict tube performance reasonably well. They are the models of Rose (modified) [Ref. 4], and Beatty and Katz [Ref. 2].

The Beatty and Katz model, which, while reasonably accurate, consistently over-predicts the experimental performance of the integral-fin tubes. This is due to the fact that Beatty and Katz neglected the effects of surface tension. In fact, the Beatty and Katz model clearly is more accurate for the atmospheric runs than it is for the vacuum runs. This is because the atmospheric runs are conducted at 100 degrees C (vice 48.7 C during vacuum conditions) where the condensate surface tension is reduced.

The modified Rose [Ref. 4] model appears to be overall the most accurate model, although it tends to under-predict the

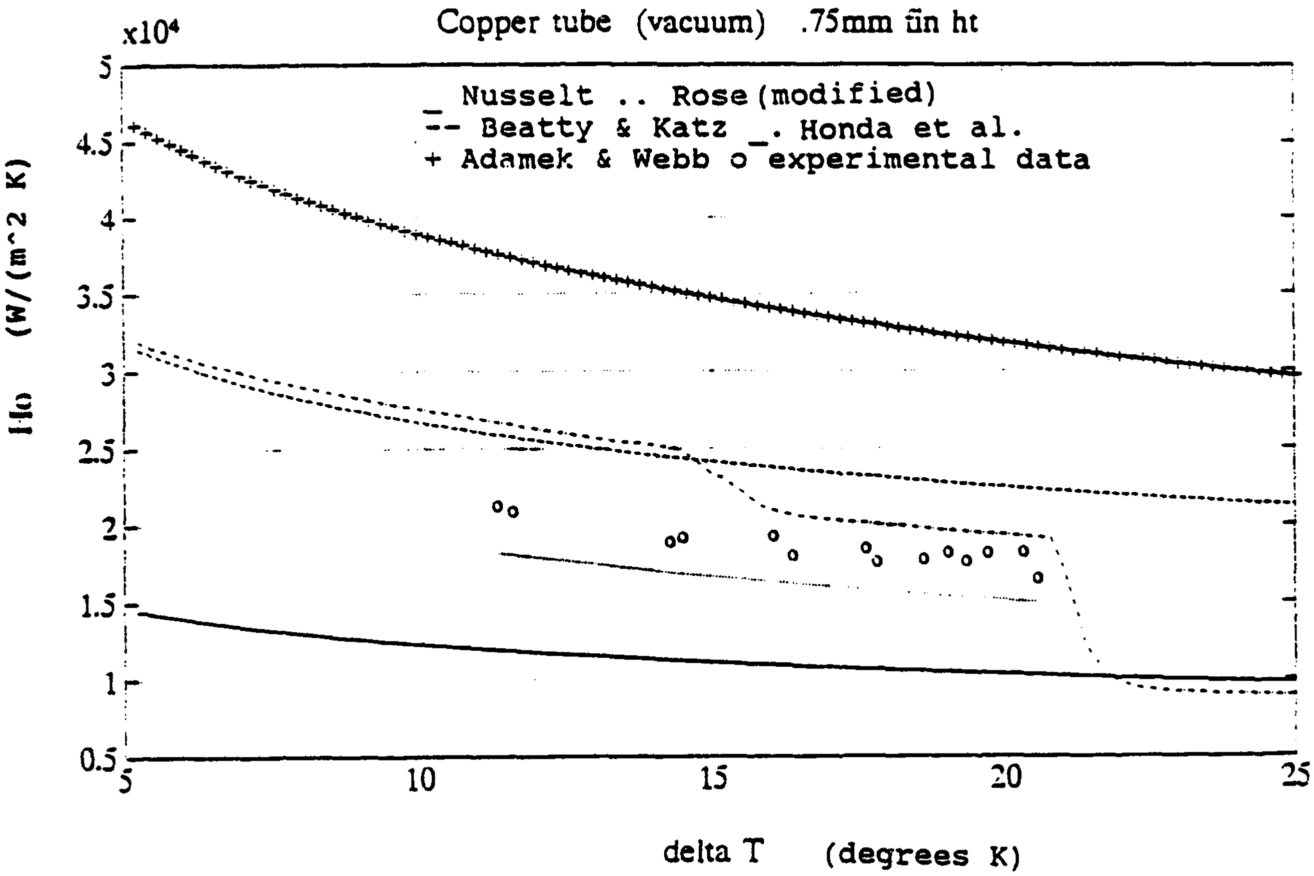


Figure 13 Experimental Results of Ho Vs. Temperature Difference for Copper Tubes at Vacuum Pressure with Predictive Models

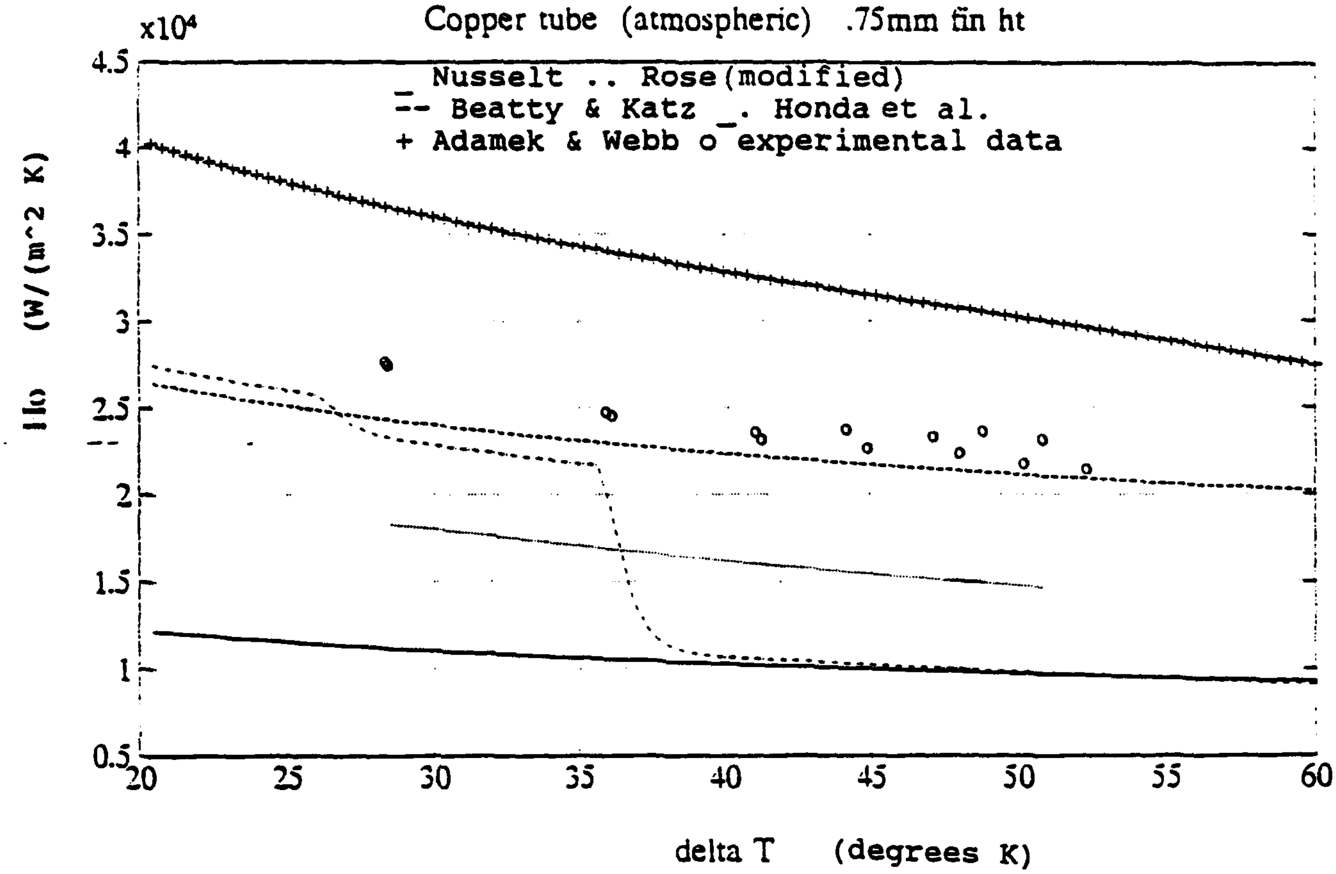


Figure 14 Experimental Results of Ho vs. Temperature Difference for Copper Tubes at Atmospheric Pressure with Predictive Models

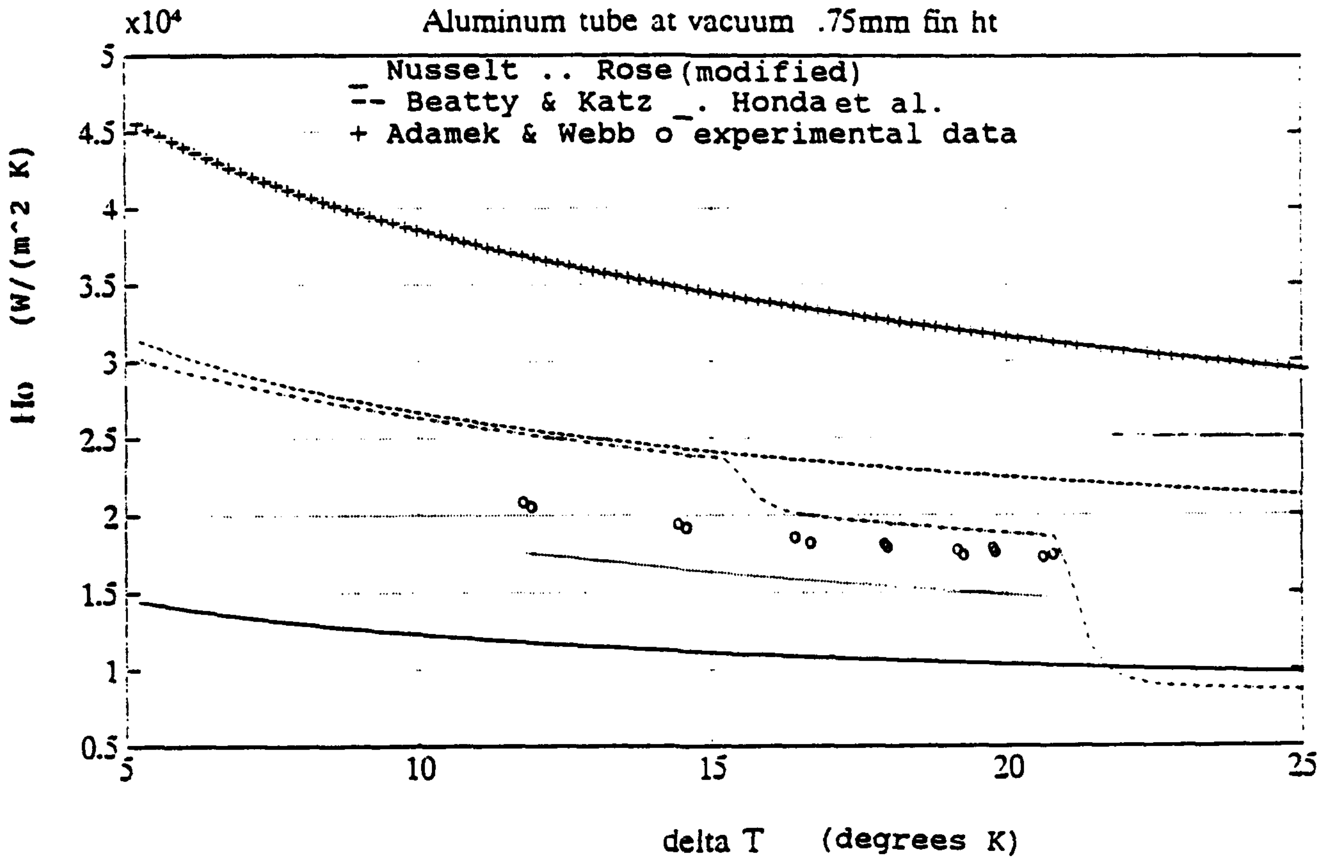


Figure 15 Experimental Results of Ho Vs. Temperature Difference for Aluminum Tubes at Vacuum Pressure with Predictive Models

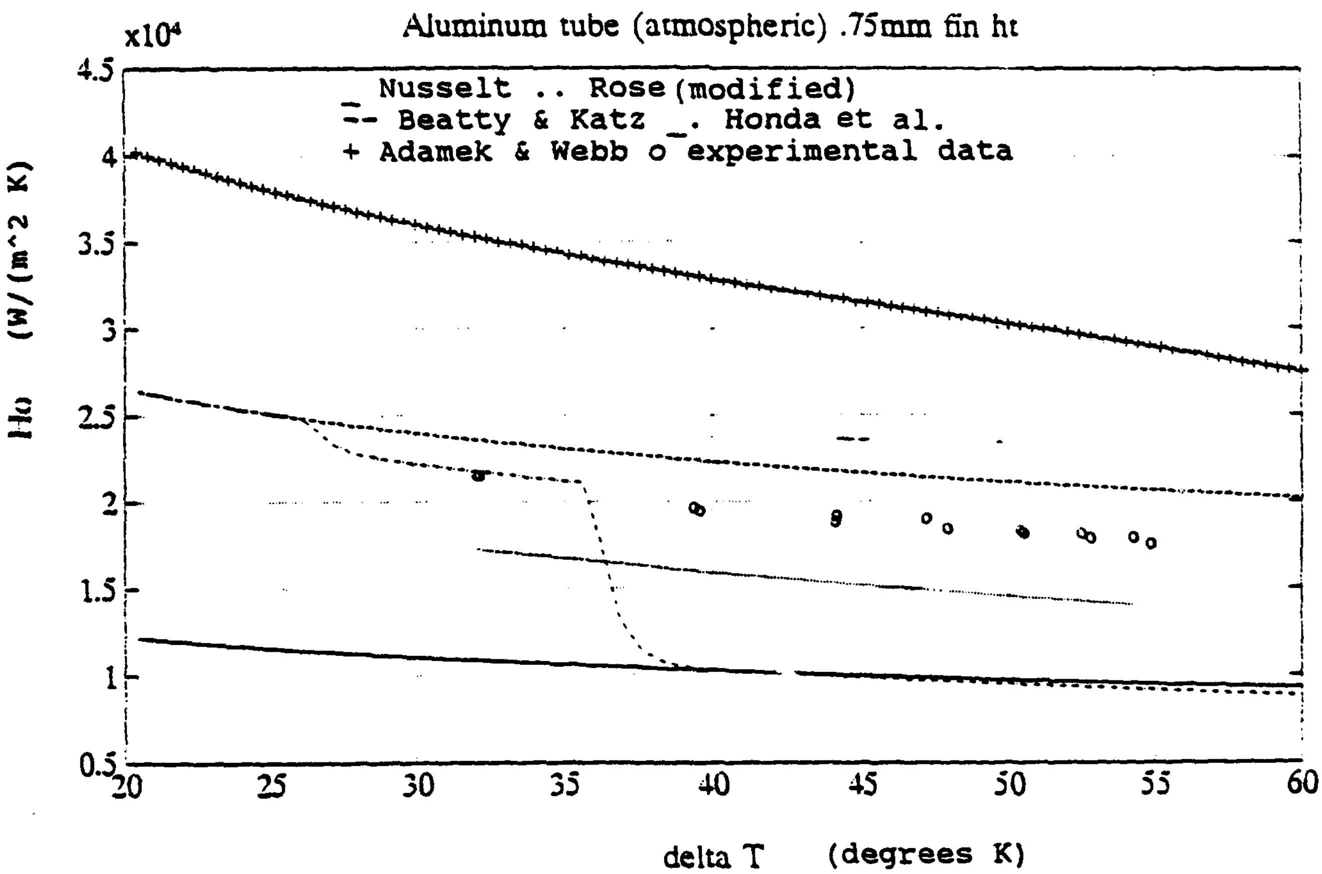


Figure 16 Experimental Results of Ho Vs. Temperature Difference for Aluminum Tubes at Atmospheric Pressure with Predictive Models

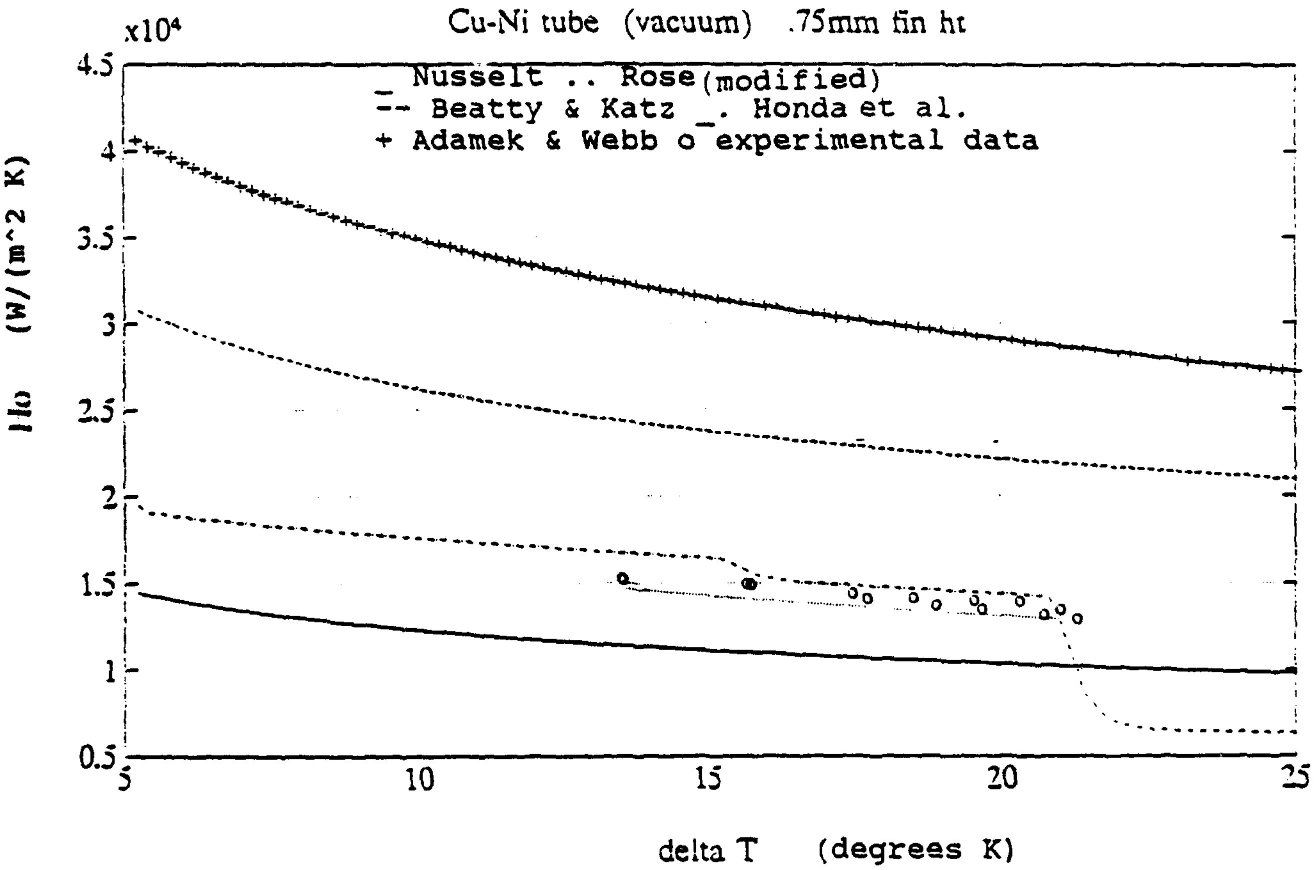


Figure 17 Experimental Results of Ho Vs. Temperature Difference for Copper-Nickel Tubes at Vacuum Pressure with Predictive Models

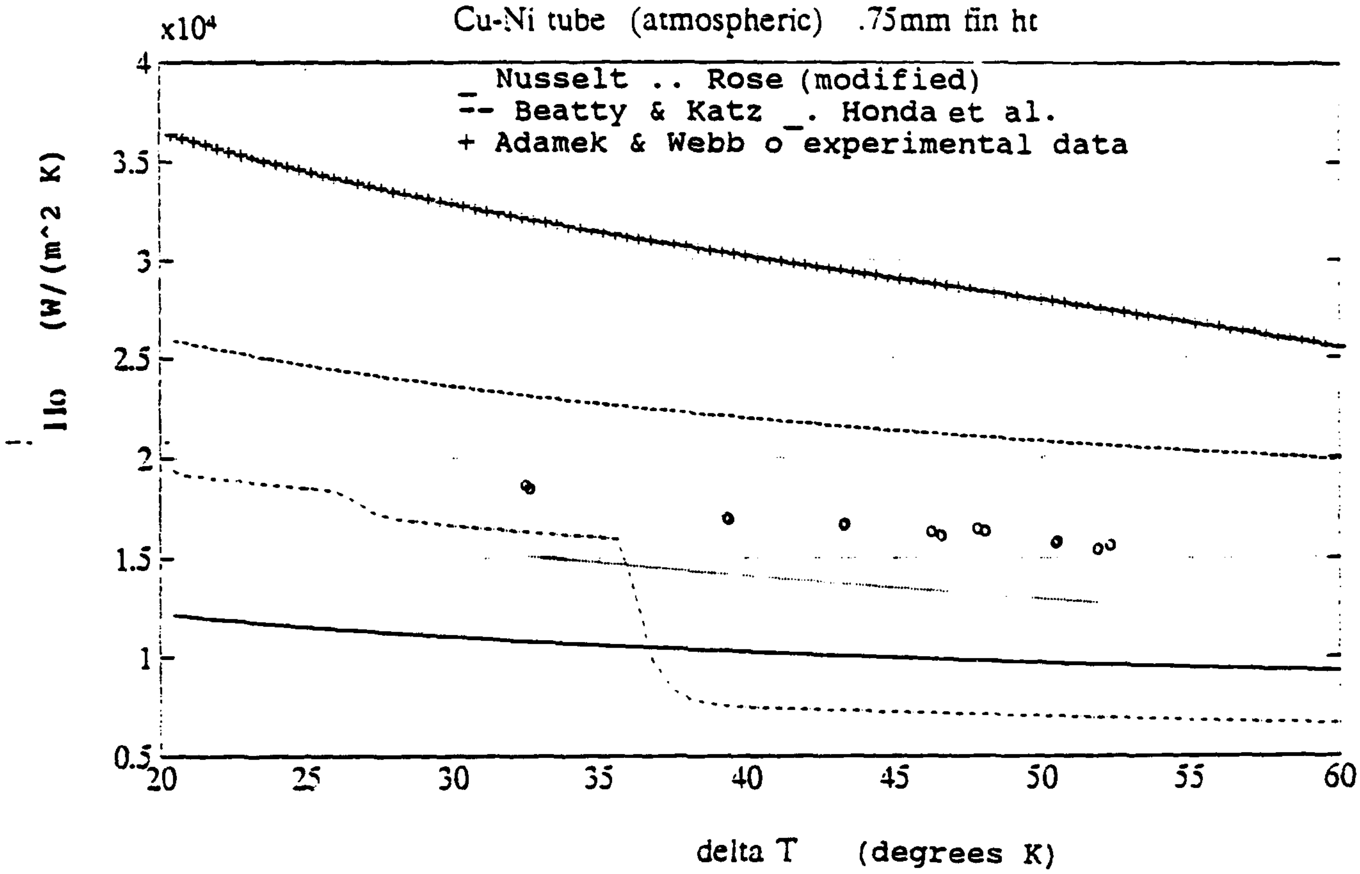


Figure 18 Experimental Results of Ho Vs. Temperature Difference for Copper-Nickel Tubes at Atmospheric Pressure with Predictive Models

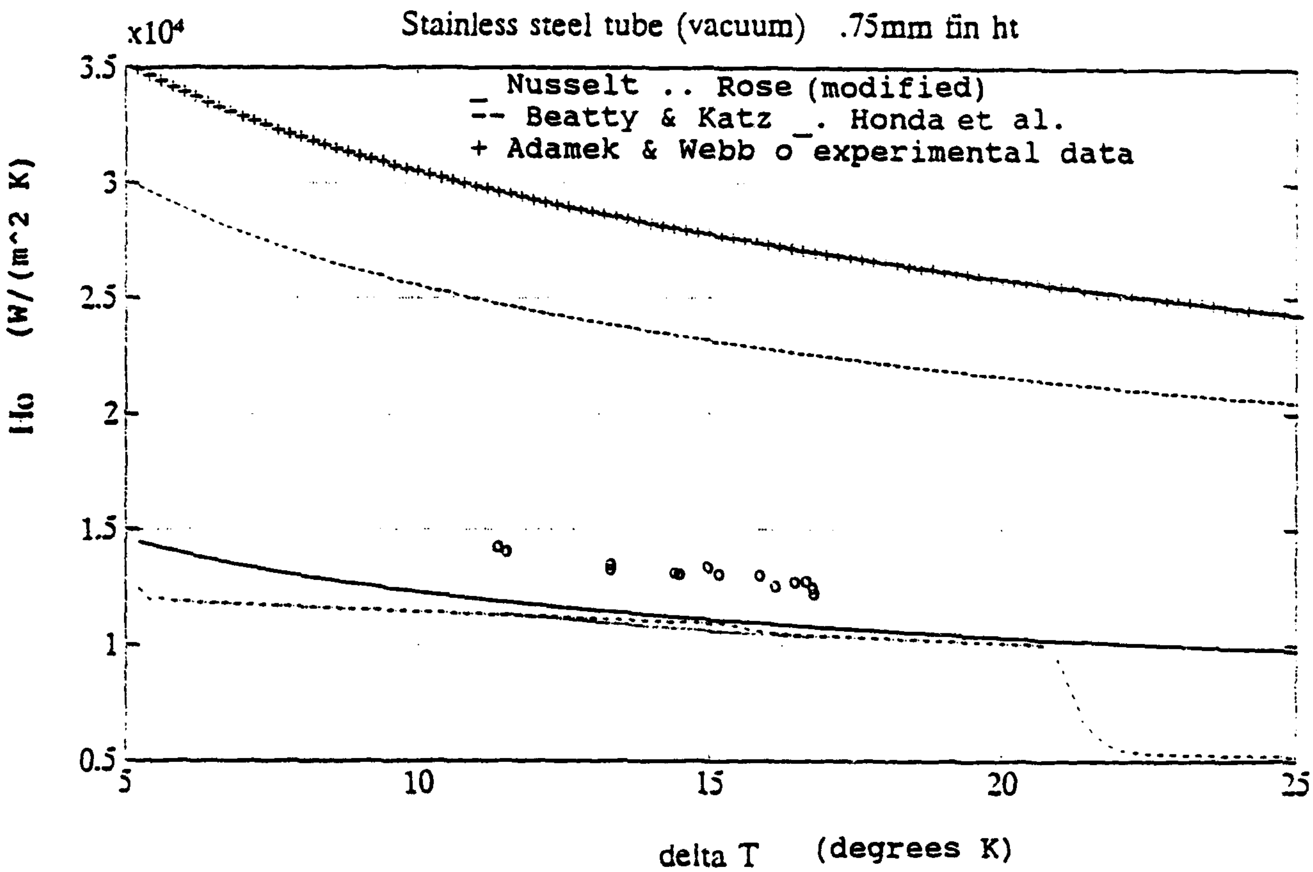


Figure 19 Experimental Results of Ho Vs. Temperature Difference for Stainless Steel Tubes at Vacuum Pressure with Predictive Models

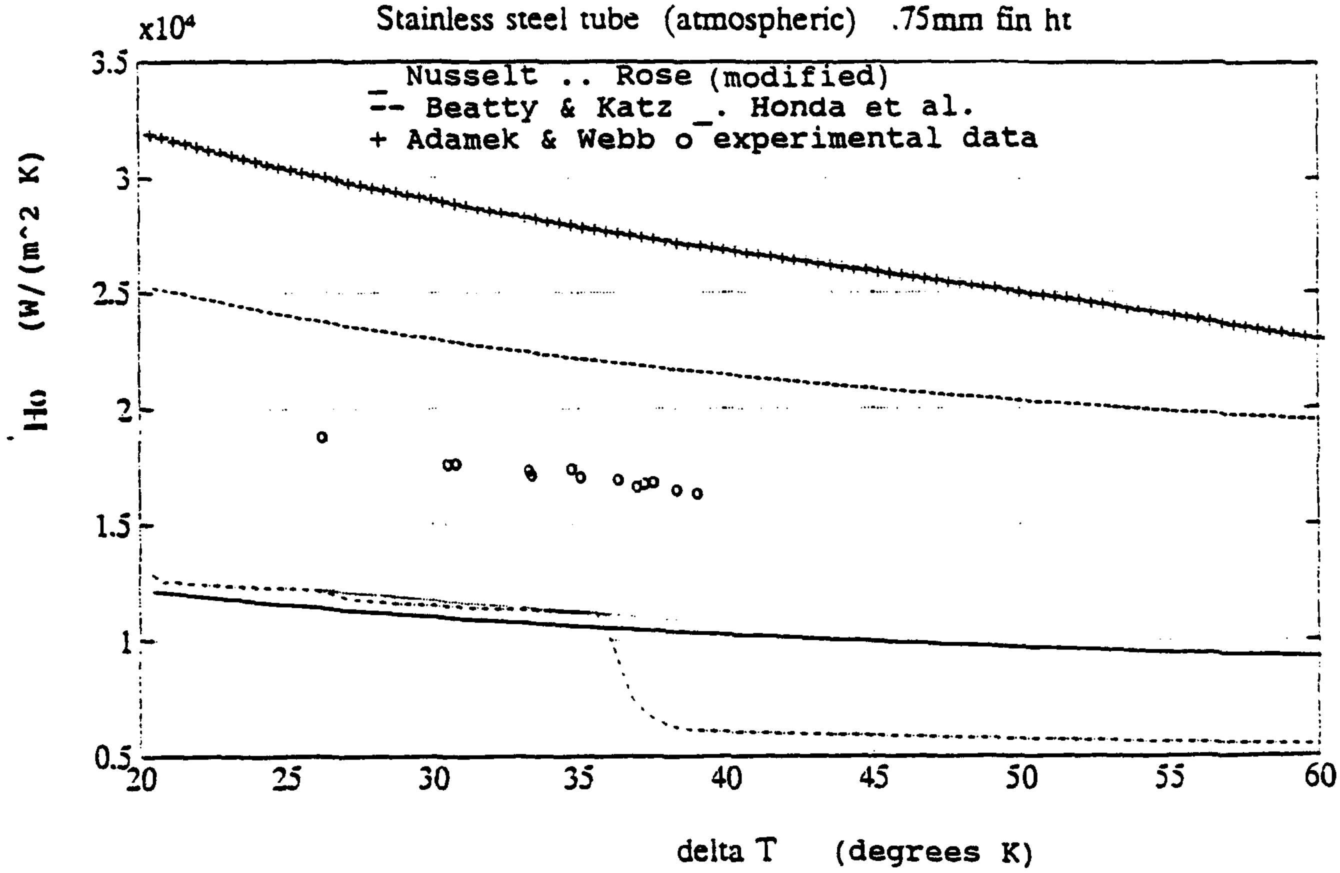


Figure 20 Experimental Results of Ho Vs. Temperature Difference for Stainless Steel Tubes at Atmospheric Pressure with Predictive Models

experimental tube performance. Of course, accuracy coupled with conservatism can be a very desirable design characteristic. Actual values of enhancement as predicted by modified Rose, experimental enhancement, and the percent difference between the two, will be presented later in tabular form.

As Figures 13 through 20 show, the Adamek and Webb [Ref. 3] model tends to excessively over-predict the performance of integral-fin tubes. Though the model displays the correct trends, the relative inaccuracy and complexity compared to the modified Rose model, would tend to render the Adamek and Webb model unusable.

The Honda et al. [Ref. 5] model demonstrates the ability to be extremely accurate, but its predictions vary widely as the model steps through its different sub-cases (the wide changes in outside heat transfer coefficient predicted by the Honda model do not seem to be borne out by the experimental results). Again, the complexity and often inaccuracy of the Honda model makes other models such as modified Rose, more appealing. The inaccuracies of the Adamek and Webb [Ref. 3] and Honda et al. [Ref.5] models may be due to errors in the codes established by Tsujimori [Ref. 11].

D. ENHANCEMENT VS. FIN HEIGHT

Figures 21 and 22 are plots of the experimental enhancement ratio versus fin height for all four tube

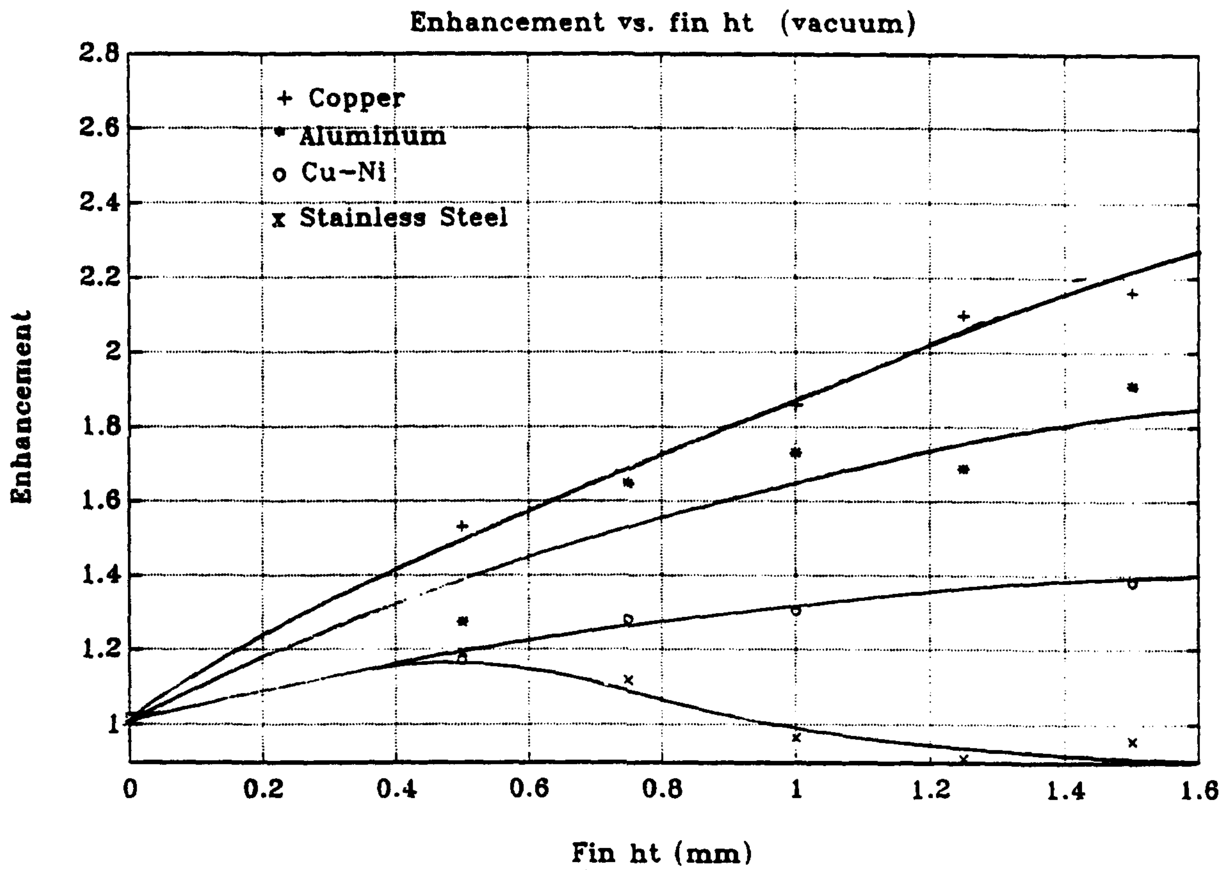


Figure 21 Experimental Results of Enhancement Vs. Fin Height for All Tubes at Vacuum Pressure

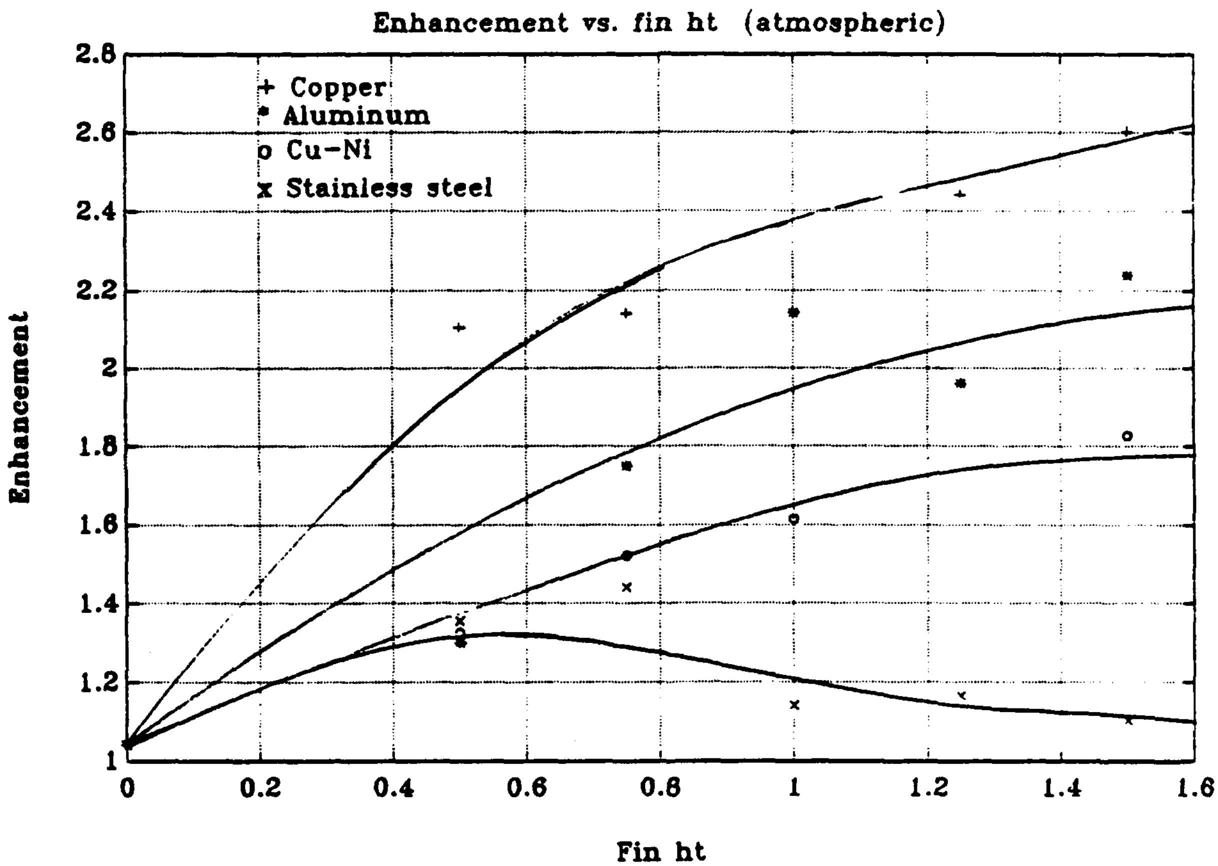


Figure 22 Experimental Results of Enhancement Vs. Fin Height for All Tubes at Atmospheric Pressure

materials. The enhancement is defined as the ratio of experimentally found outside heat transfer coefficient at a given temperature difference, over the outside heat transfer coefficient for the same temperature difference as predicted by Nusselt. There are three major points which can be derived from these plots:

1. **Smooth Tube Performance**

For the copper and aluminum smooth tubes (ie fin height equal to zero), one can see a slight enhancement over that predicted by Nusselt. This is due to the fact that contrary to Nusselt's assumption of a quiescent vapor, there is a downward vapor velocity associated with the experimental data (approximately 2 m/s for vacuum runs and 1 m/s for the atmospheric runs). This vapor velocity tends creates a shear force that thins the condensate film and enhances heat transfer.

2. **Effect of Fin Height on Enhancement**

Again, particularly for high conductivity materials, as fin height increases, so does performance. For example, for copper and aluminum tubes, one can see an increasing enhancement up to a fin height of 1.5mm, and the data appear to demonstrate that a further increase in enhancement may occur if fin height is further increased. However, this is not so for low conductivity materials as discussed in the next section.

3. Effect of Conductivity on Enhancement

Low thermal conductivity materials severely reduce enhancement. As can be seen in Figures 21 and 22, raising the fin height would not necessarily result in further enhanced performance. Even for a material with an intermediate thermal conductivity, such as copper-nickel (see Figure 21), beyond a fin height of about 0.75mm, there is little increase in the enhancement. For stainless steel, the enhancement decreases for a fin height above 0.5 - 0.75mm, depending on the operating conditions.

In the present study, the minimum fin height used was 0.5mm. For stainless steel, it is observed that under vacuum conditions, the enhancement peaks at a fin height of 0.5mm and decreases for larger values. A recent work by Jaber and Webb [Ref. 6], shows that for titanium tubes, which have a conductivity near that of stainless steel, the enhancement increases with increasing fin height of 0.28 and 0.43mm. It appears that for such tubes, 0.5mm fin height would result in an optimum performance. However, more experimentation with lower fin heights is required before any firm conclusions can be reached.

E. COMPARISON OF ENHANCEMENT WITH THE ROSE (MODIFIED) MODEL

Figures 23 through 30 are plots of enhancement versus fin height and compare the experimental data to the predictive results of the modified Rose model. Note that for all the

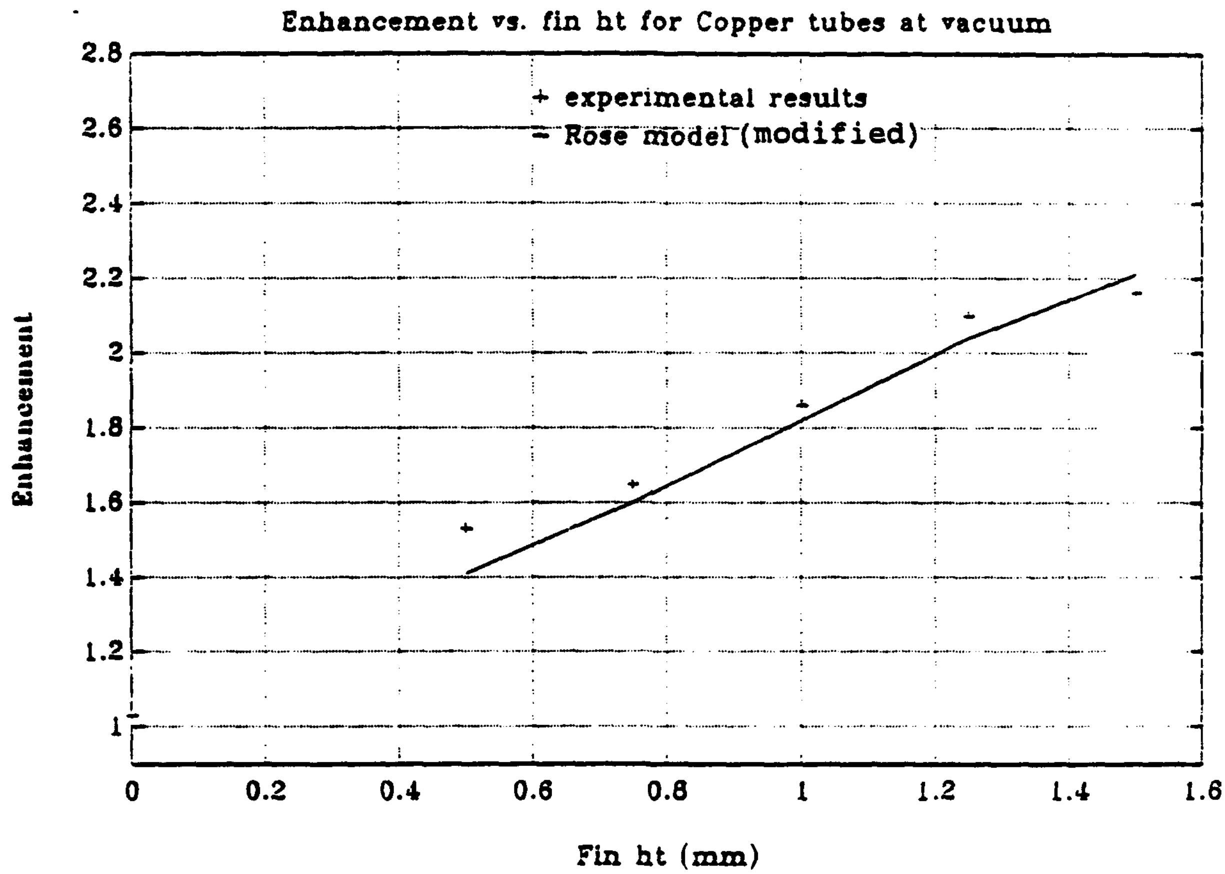


Figure 23 Experimental Results of Enhancement Vs. Fin Height for Copper Tubes at Vacuum with the Rose Model

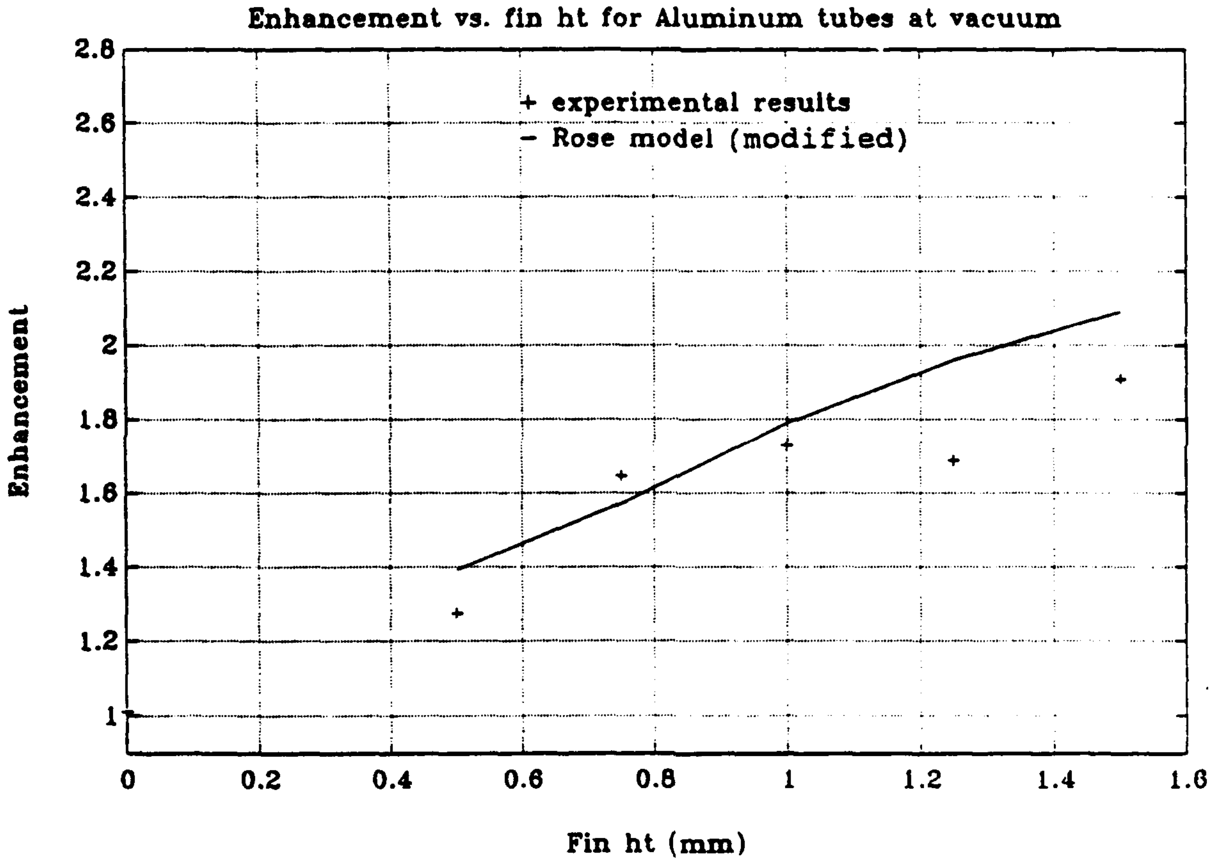


Figure 24 Experimental Results of Enhancement Vs. Fin Height for Aluminum Tubes at Vacuum with the Rose Model

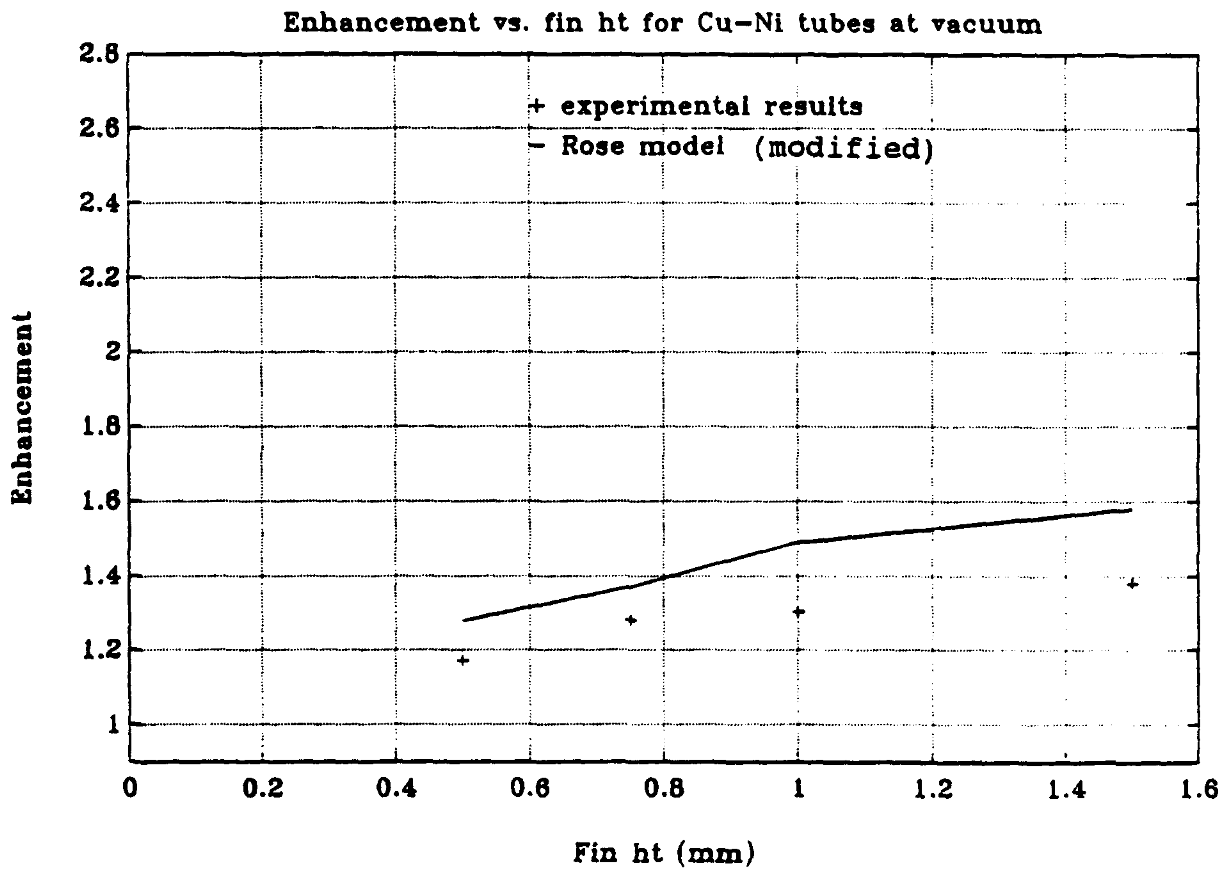


Figure 25 Experimental Results of Enhancement Vs. Fin Height for Copper-Nickel Tubes at Vacuum with the Rose Model

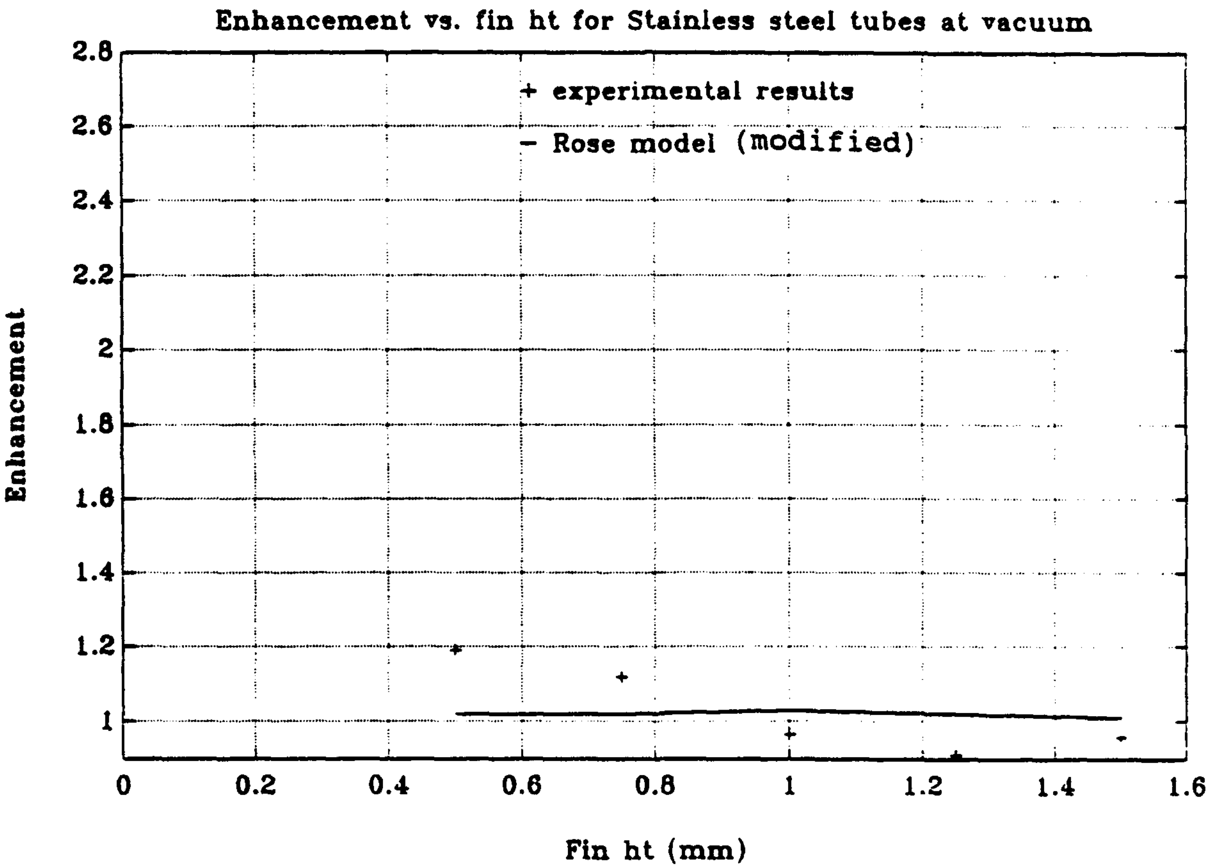


Figure 26 Experimental Results of Enhancement Vs. Fin Height for Stainless Steel Tubes at Vacuum with the Rose Model

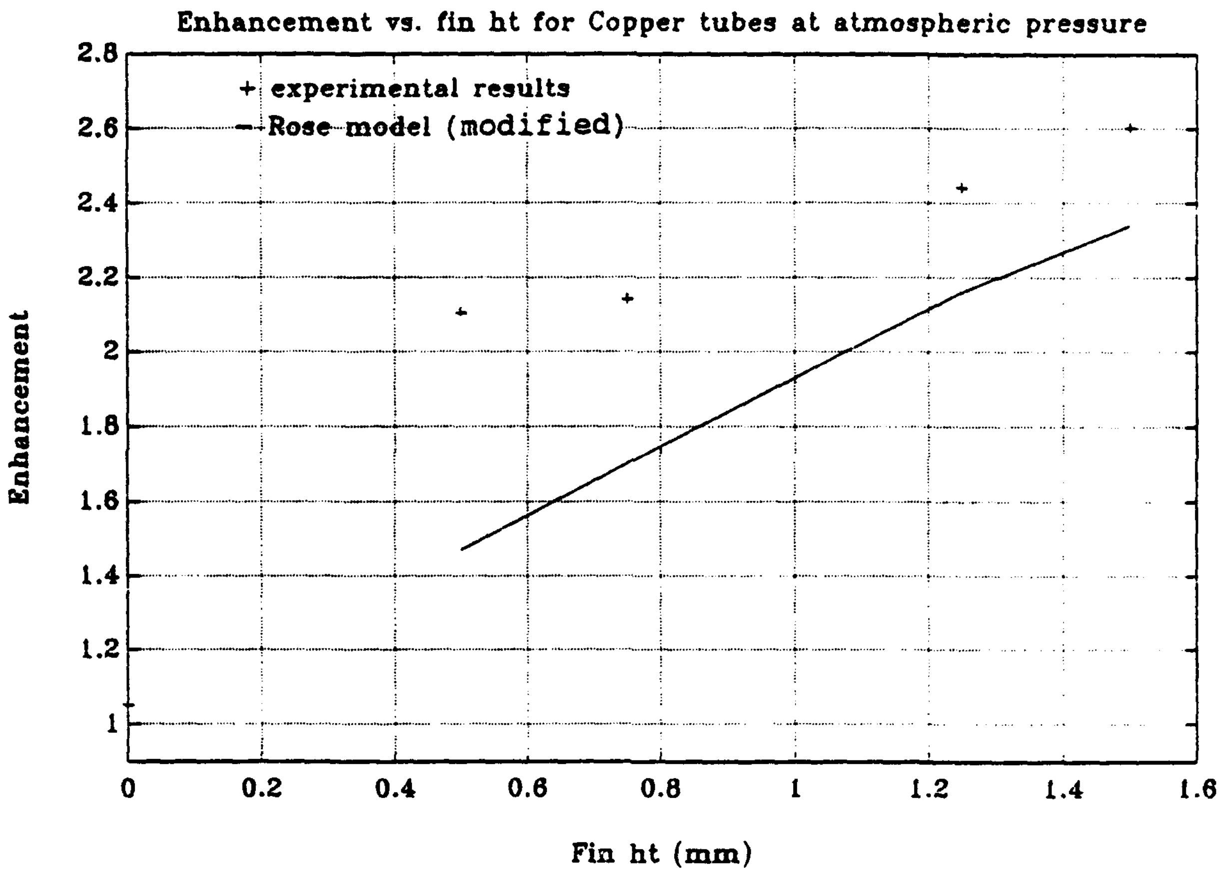


Figure 27 Experimental Results of Enhancement Vs. Fin Height for Copper Tubes at Atmospheric Pressure with the Rose Model

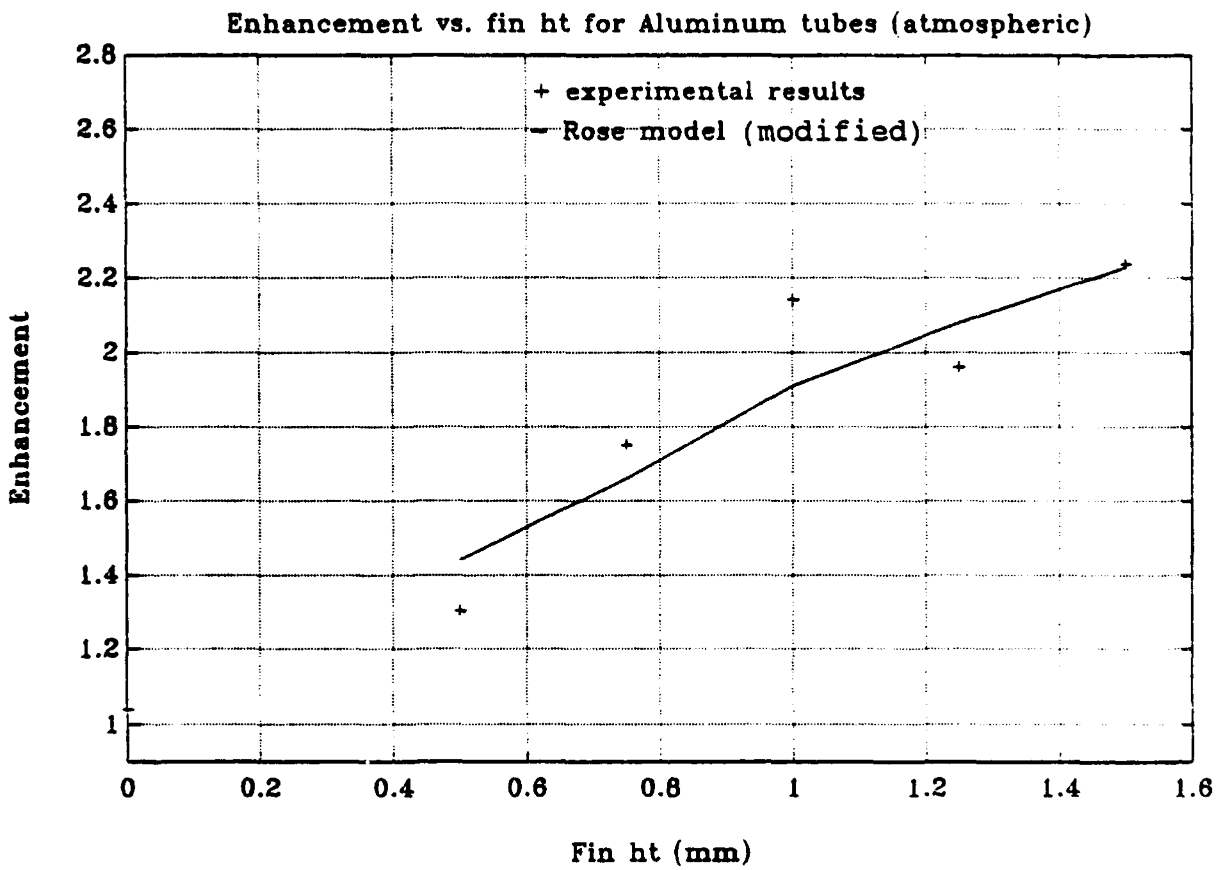


Figure 28 Experimental Results of Enhancement Vs. Fin Height for Aluminum Tubes at Atmospheric Pressure with the Rose Model

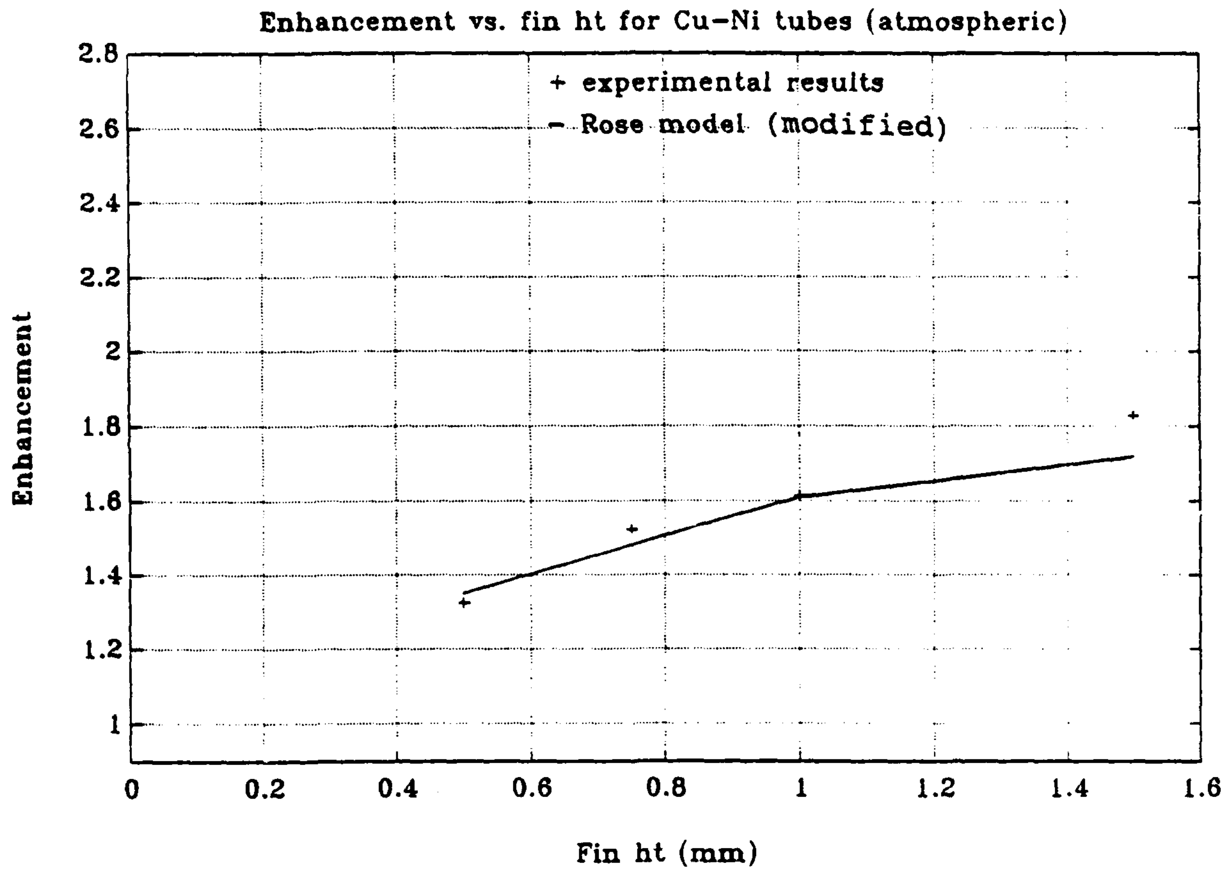


Figure 29 Experimental Results of Enhancement Vs. Fin Height for Copper-Nickel Tubes at Atmospheric Pressure with the Rose Model

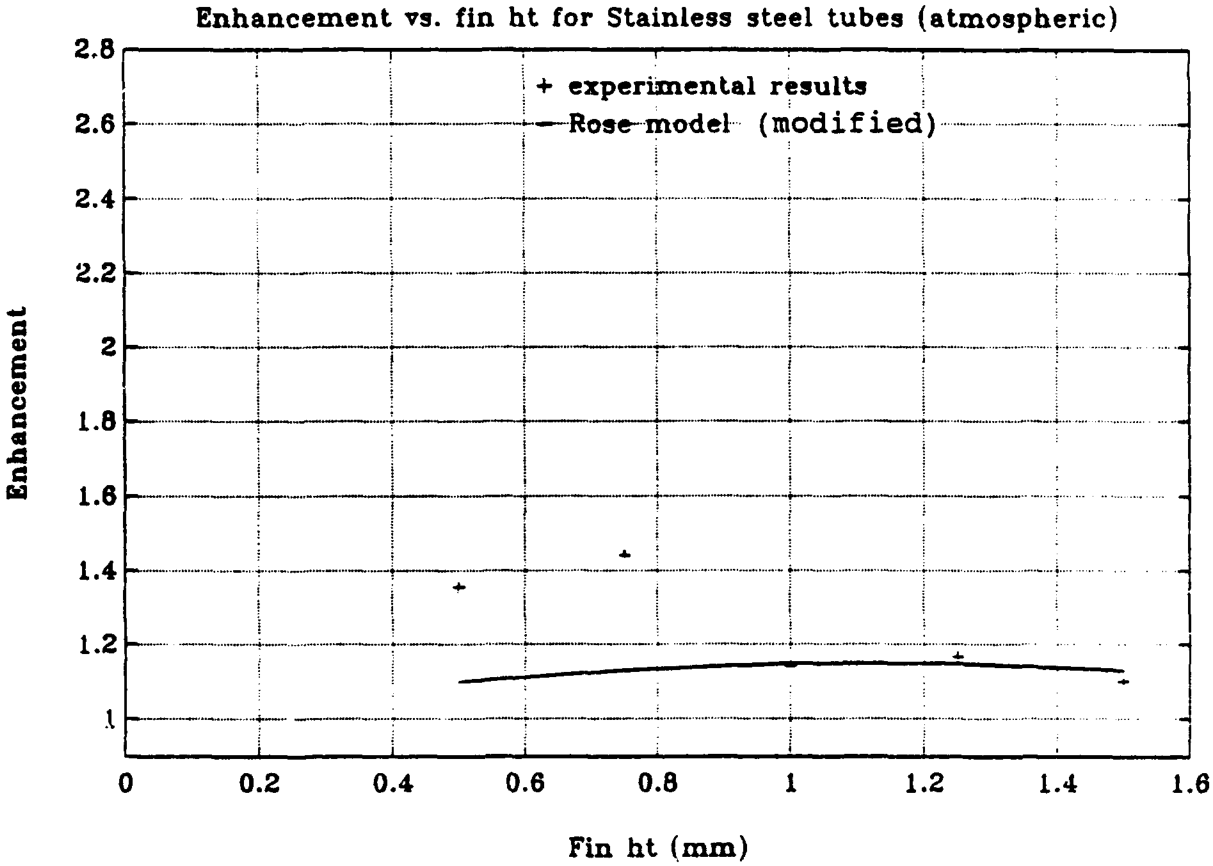


Figure 30 Experimental Results of Enhancement Vs. Fin Height for Stainless Steel Tubes at Atmospheric Pressure with the Rose Model

plots, the modified Rose model demonstrates a reasonable to very good predictive capability. The only glaring shortcoming of the Rose model is its inability to predict the performance peaks of stainless steel at low fin heights (Figures 26 & 30).

Surprisingly, even though the original Rose model was developed using experimental data for copper tubes at atmospheric pressure, the modified Rose model works well for all tube materials. In addition, one might expect, that the modified Rose model would work best for copper tubes at atmospheric pressure, when in fact, this is not the case. This may be at least partially explained by recognizing that the B coefficients for the Rose model were determined without taking into account fin efficiency. Adding a fin efficiency to create the modified Rose model would then make the coefficients incorrect since they essentially include the effects of copper fin efficiency, assumed to be unity. Accuracy of the modified Rose model improves for conductivities less than that of copper, probably because the effects of fin efficiency become increasingly predominant.

Table IV. compares enhancement for a given experimental data run to the average enhancement as predicted by Rose (modified) for the same film temperature difference.

Note that with very few exceptions, the modified Rose model was able to predict the experimental data with good accuracy. The few exceptions may be more an indication of experimental error than of problems with Rose's (modified)

model. The potential of the modified Rose model warrants more experimental data to further establish its validity.

TABLE IV. EXPERIMENTAL AND ROSE MODEL ENHANCEMENTS

TUBE TYPE	EXP	ROSE (MODIFIED)	% DIFF.
CU5	1.53	1.41	7.8
CU75	1.65	1.60	3.0
CU1	1.86	1.82	2.1
CU125	2.10	2.04	2.8
CU15	2.16	2.21	2.3
AL5	1.27	1.39	9.4
AL75	1.65	1.57	4.8
AL1	1.73	1.79	3.5
AL125	1.69	1.96	15.0
AL15	1.91	2.09	9.4
CN5	1.17	1.28	9.4
CN75	1.28	1.37	7.0
CN1	1.30	1.49	14.6
CN15	1.38	1.58	14.5

TUBE TYPE	EXP	ROSE (MODIFIED)	% DIFF.
SS5	1.20	1.02	15.0
SS75	1.12	1.02	8.9
SS1	0.96	1.03	6.7
SS125	0.91	1.02	12.1
SS15	0.96	1.01	5.2
CU5A	2.11	1.47	30.3
CU75A	2.14	1.70	20.5
CU125A	2.44	2.16	11.5
CU15A	2.60	2.34	10.0
AL5A	1.30	1.44	10.8
AL75A	1.75	1.66	5.1
AL1A	2.14	1.91	6.1
AL125A	1.96	2.08	6.1
AL15A	2.24	2.23	0.4
CN5A	1.32	1.35	2.3
CN75A	1.52	1.48	2.6
CN1A	1.61	1.61	0.0

TUBE TYPE	EXP	ROSE (MODIFIED)	% DIFF.
CN15A	1.83	1.72	6.0
SS5A	1.36	1.10	19.1
SS75A	1.44	1.13	21.5
SS1A	1.14	1.15	0.9
SS125A	1.17	1.15	1.7
SS15A	1.10	1.13	2.7

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Experimental data were obtained for steam condensation on integral-fin tubes made of copper, aluminum, 90/10 copper-nickel, and 316 stainless steel at both atmospheric and vacuum conditions. The tubes used had a root diameter of 13.88mm, a fin thickness of 1.0mm, a fin spacing of 1.5mm and fin heights ranging from 0.5mm to 1.5mm, in 0.25mm increments. From this data, the following conclusions can be made:

1. Reliable, repeatable data have been obtained, on the performance of integral-fin tubes of varying materials and fin heights.

2. For high conductivity materials, such as copper or aluminum, as fin height increases so does the enhancement of performance.

3. For low conductivity materials, such as stainless steel,the effect of increasing surface area for heat transfer by raising fin height, is negated by both the poor fin efficiency, and the increased flooded area of the tube, resulting in a decrease in heat transfer performance.

4. Of the examined predictive models, the modified Rose model seems to be the most accurate. This is despite the fact that his empirically determined coefficients were found only with data for a copper tube at atmospheric pressure.

B. RECOMMENDATIONS

1. Use the results from tubes tested in this work and in future work, to evaluate the B coefficients in the modified Rose model to determine if the B values need to be changed.

2. Test tubes at a fin height of 1mm with a fin spacing ranging from 0.5mm to 2.0mm to find a spacing which maximizes heat transfer enhancement for each tube material.

3. Test tubes at a fin height of 1mm with a fin thickness ranging from 0.25mm to 1.5mm to find a fin thickness which maximizes heat transfer enhancement for each tube material.

4. Using the results from 2 and 3, find the ideal fin configuration which maximizes heat transfer enhancement for each tube material.

5. Experimentally determine how changing the root diameter of a tube changes the results in 4.

6. Continue with the computer upgrade in progress, to ensure faster, more timely analysis.

7. Install a sight glass defogger on the test apparatus to enable the operator to easily visualize the tube during testing.

8. Install a throttle valve to more precisely regulate the cooling water flow through the test tube.

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APPENDIX A. - PROGRAM DRPALL

The computer program DRPALL, is a program written in HP Basic 3.0 which drives the HP 3497 Data Acquisition Unit. DRPALL takes the raw data, and using the Modified Wilson Plot Technique, calculates the test tube outside heat transfer coefficient. DRPALL also takes into account frictional heating of the test tube coolant, as well as tube end effects (ie it considers the fact that the two ends of the test tube act like fins).

More information on program DRPALL can be obtained by contacting:

Prof. Paul J. Marto, Code ME/Mx
Department of Mechanical Engineering
Naval Postgraduate School
Monterey Ca. 93943-5002

APPENDIX B. - PROGRAM HEATMEYER

HEATMEYER is the program which predicts the outside heat transfer coefficient, and enhancement of integral-fin tubes based on the modified Rose model [Ref. 4]. HEATMEYER is a slight alteration of Cobb's HEATCOBB [Ref. 8]. More information on program HEATMEYER can be obtained by contacting:

Prof. Paul J. Marto, Code ME/Mx
Department of Mechanical Engineering
Naval Postgraduate School
Monterey Ca. 93943-5002

APPENDIX C. - TSUJIMORI COMPUTER CODES

These codes, written by Tsujimori [Ref. 11] are written in the "C" computer language. There are a total of three individual programs. One program for Nusselt [Ref. 1] (as a reference), as well as Beatty and Katz [Ref. 2], one program for the Adamek and Webb [Ref. 3] model, and the last program for the Honda et al. [Ref. 5] model.

All three programs are interactive and are written such that the user may specify the test tube parameters for any tube without having to alter the program. All three programs generate data files of heat transfer coefficient vs. temperature difference, as well as enhancement ratio vs. temperature difference or heat flux or fin spacing. For more information on the Tsujimori codes, contact:

Prof. Paul J. Marto, Code ME/Mx
Department of Mechanical Engineering
Naval Postgraduate School
Monterey, Ca 93943-5002

APPENDIX D. - EXPERIMENTAL DATA

This Appendix has short form printouts, generated by program DRPALL, for all data runs taken.

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CU15
This analysis includes end-fin effect
Thermal conductivity = 390.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7667
Alpha (based on Nusselt (Tdel)) = 1.5089
Enhancement (q) = 2.437
Enhancement (Del-T) = 1.986

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.440E+04	2.173E+04	3.902E+05	17.36	48.56
2	3.81	1.410E+04	2.221E+04	3.805E+05	17.13	48.58
3	3.28	1.362E+04	2.256E+04	3.698E+05	16.39	48.66
4	2.75	1.306E+04	2.314E+04	3.535E+05	15.28	48.83
5	2.22	1.217E+04	2.334E+04	3.293E+05	14.11	48.64
6	1.69	1.110E+04	2.407E+04	3.008E+05	12.50	48.87
7	1.16	9.723E+03	2.637E+04	2.611E+05	9.90	48.77

Least-squares line for q = a*delta-T^b
a = 4.5473E+04
b = 7.5000E-01

NOTE: 07 data points were stored in file CU15

NOTE: 07 X-Y pairs were stored in data file

NOTE: Program name : CRPALL
Data taken by : MEYER
This analysis done on file : CU125R
This analysis includes end-fin effect
Thermal conductivity = 390.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8749
Alpha (based on Nusselt (Tdel)) = 1.4671
Enhancement (q) = 2.208
Enhancement (Del-T) = 1.811

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	1.322E+04	1.806E+04	3.853E+05	20.75	48.72
2	3.83	1.279E+04	1.800E+04	3.820E+05	20.00	48.68
3	3.30	1.251E+04	1.853E+04	3.715E+05	19.02	48.55
4	2.77	1.203E+04	1.893E+04	3.551E+05	17.82	48.46
5	2.23	1.151E+04	2.082E+04	3.362E+05	16.15	48.28
6	1.70	1.047E+04	2.103E+04	3.049E+05	14.50	48.38
7	1.17	9.251E+03	2.263E+04	2.665E+05	11.78	48.43

Least-squares line for q = a*delta-T^b
a = 4.1037E+04
b = 7.5000E-01

NOTE: 07 data points were stored in file CU125R

NOTE: 07 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CU75
This analysis includes end-fin effect
Thermal conductivity = 390.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4072
Alpha (based on Nusselt (Tdel)) = 1.3344
Enhancement (q) = 1.946
Enhancement (Del-T) = 1.647

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tcf (C)	Ts (C)
1	4.36	1.139E+04	1.650E+04	3.397E+05	20.58	48.70
2	3.83	1.150E+04	1.760E+04	3.406E+05	19.35	48.43
3	3.30	1.108E+04	1.772E+04	3.296E+05	18.60	48.64
4	2.77	1.044E+04	1.755E+04	3.123E+05	17.80	48.35
5	2.23	9.848E+03	1.796E+04	2.940E+05	16.37	48.78
6	1.70	9.114E+03	1.888E+04	2.639E+05	14.29	48.48
7	1.17	9.134E+03	2.125E+04	2.412E+05	11.35	48.66
8	1.17	9.073E+03	2.088E+04	2.429E+05	11.62	49.00
9	1.70	9.160E+03	1.916E+04	2.777E+05	14.50	48.73
10	2.24	1.019E+04	1.825E+04	3.086E+05	16.04	48.51
11	2.77	1.071E+04	1.844E+04	3.248E+05	17.61	48.33
12	3.30	1.122E+04	1.818E+04	3.460E+05	19.03	48.76
13	3.83	1.170E+04	1.814E+04	3.577E+05	19.72	48.68
14	4.37	1.214E+04	1.820E+04	3.699E+05	20.33	48.58

Least-squares line for q = a*delta-T^b
a = 3.7401E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CU75

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : CRPALL
      Data taken by                 : MEYER
      This analysis done on file : CU5
      This analysis includes end-fin effect
      Thermal conductivity       = 390.3 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petuknov-Popov coefficient    = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)    =  2.3144
Alpha (based on Nusselt (Tdel)) =  1.2401
Enhancement (q)                 =  1.764
Enhancement (Del-T)             =  1.531
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	1.090E+04	1.582E+04	3.383E+05	21.33	43.75
2	3.84	1.058E+04	1.587E+04	3.255E+05	20.57	43.81
3	3.30	1.043E+04	1.554E+04	3.188E+05	19.27	43.42
4	2.77	9.918E+03	1.633E+04	3.015E+05	18.46	43.67
5	2.24	9.256E+03	1.665E+04	2.833E+05	17.01	43.57
6	1.70	8.445E+03	1.690E+04	2.566E+05	15.19	43.63
7	1.17	7.628E+03	1.920E+04	2.311E+05	12.03	43.39
8	1:17	7.670E+03	1.947E+04	2.317E+05	11.90	43.30
9	1.70	8.789E+03	1.834E+04	2.665E+05	14.53	43.51
10	2.24	9.370E+03	1.703E+04	2.860E+05	16.80	43.54
11	2.77	1.006E+04	1.702E+04	3.065E+05	18.01	43.43
12	3.30	1.043E+04	1.663E+04	3.209E+05	19.23	43.42
13	3.83	1.083E+04	1.657E+04	3.332E+05	20.11	43.65
14	4.37	1.110E+04	1.622E+04	3.383E+05	20.90	43.57

```
Least-squares line for q = a*delta-T^b
  a =  3.4666E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file CU5

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : ORPALL
      Data taken by : MEYER
      This analysis done on file : CUSMT
      This analysis includes end-fin effect
      Thermal conductivity = 390.8 (W/m.K)
      Inside diameter, Di = 12.70 (mm)
      Outside diameter, Do = 14.38 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petuknov-Popov coefficient = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement : SMOOTH TUBE
      Tube material : COPPER
      Pressure condition : VACUUM
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3990
Alpha (based on Nussalt (Tdel)) = 0.8362
Enhancement (q) = 1.043
Enhancement (Del-T) = 1.032

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	7.796E+03	1.003E+04	2.388E+05	23.65	48.45
2	3.83	7.636E+03	1.013E+04	2.346E+05	23.16	48.66
3	3.30	7.658E+03	1.053E+04	2.342E+05	22.11	48.42
4	2.77	7.452E+03	1.078E+04	2.277E+05	21.13	48.43
5	2.24	7.119E+03	1.031E+04	2.176E+05	19.95	48.52
6	1.70	6.636E+03	1.103E+04	2.043E+05	18.52	48.95
7	1.17	6.055E+03	1.173E+04	1.823E+05	15.54	48.61
8	1.17	6.070E+03	1.179E+04	1.835E+05	15.57	48.74
9	1.70	6.573E+03	1.116E+04	2.037E+05	19.25	48.60
10	2.24	7.035E+03	1.071E+04	2.164E+05	20.20	48.65
11	2.77	7.480E+03	1.084E+04	2.233E+05	21.16	48.45
12	3.30	7.653E+03	1.053E+04	2.353E+05	22.23	48.53
13	3.84	7.779E+03	1.038E+04	2.403E+05	23.15	48.77
14	4.37	7.812E+03	1.012E+04	2.432E+05	24.03	48.97

Least-Squares Line for Ho vs q curve:
  Slope = 0.0000E+00
  Intercept = 0.0000E+00

Least-squares line for q = a*delta-T^b
  a = 2.2883E+04
  b = 7.5000E-01

```
NOTE: Program name : DRPALL
      Data taken by                : MEYER
      This analysis done on file : CU1SA
      This analysis includes end-fin effect
      Thermal conductivity       = 390.8 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov)     =  3.1973
Alpha (based on Nusselt (Tdel)) =  2.2116
Enhancement (q)                  =  3.579
Enhancement (Del-T)              =  2.602
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	1.753E+04	2.687E+04	1.239E+06	48.34	99.95
2	3.79	1.715E+04	2.737E+04	1.258E+06	45.96	99.97
3	3.26	1.656E+04	2.770E+04	1.209E+06	43.65	100.30
4	2.74	1.596E+04	2.859E+04	1.149E+06	40.19	99.86
5	2.21	1.495E+04	2.911E+04	1.077E+06	36.99	100.12
6	1.68	1.391E+04	3.125E+04	9.893E+05	31.65	100.05
7	1.16	1.225E+04	3.476E+04	8.588E+05	24.70	99.98
8	1.16	1.221E+04	3.454E+04	8.575E+05	24.83	99.93
9	1.68	1.397E+04	3.155E+04	9.883E+05	31.35	99.72
10	2.21	1.535E+04	3.063E+04	1.098E+06	35.84	99.84
11	2.73	1.639E+04	2.989E+04	1.170E+06	39.16	99.77
12	3.26	1.724E+04	2.951E+04	1.243E+06	42.12	100.25
13	3.78	1.811E+04	2.959E+04	1.234E+06	43.73	100.12
14	4.31	1.866E+04	2.926E+04	1.334E+06	45.61	100.20

```
Least-squares line for q = a*delta-T^b
  a =  7.4074E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file CU1SA

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CU12SA
This analysis includes end-fin effect
Thermal conductivity = 390.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nussalt theory is used for Ho

Ci (based on Petukhov-Popov) = 3.2004
Alpha (based on Nussalt (Tdel)) = 2.0747
Enhancement (q) = 3.236
Enhancement (Del-T) = 2.441

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tof (C)	Ts (C)
1	4.33	1.668E+04	2.502E+04	1.257E+06	50.24	100.04
2	3.80	1.612E+04	2.495E+04	1.205E+06	48.30	100.09
3	3.27	1.567E+04	2.551E+04	1.172E+06	45.95	100.17
4	2.74	1.500E+04	2.594E+04	1.114E+06	42.93	99.86
5	2.22	1.422E+04	2.684E+04	1.051E+06	39.15	99.89
6	1.69	1.323E+04	2.856E+04	9.586E+05	33.91	99.87
7	1.16	1.174E+04	3.182E+04	8.507E+05	26.74	100.14
8	1.16	1.174E+04	3.184E+04	8.526E+05	26.77	100.27
9	1.69	1.332E+04	2.902E+04	9.793E+05	33.75	100.07
10	2.22	1.455E+04	2.805E+04	1.078E+06	38.45	100.05
11	2.75	1.552E+04	2.755E+04	1.154E+06	41.89	99.97
12	3.27	1.631E+04	2.723E+04	1.211E+06	44.46	99.76
13	3.80	1.705E+04	2.713E+04	1.254E+06	46.22	99.84
14	4.32	1.766E+04	2.708E+04	1.238E+06	47.31	99.93

Least-squares line for q = a*delta-T^b
a = 6.9127E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CU12SA

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CU75A
This analysis includes end-fin effect
Thermal conductivity = 390.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.9237
Alpha (based on Nusselt (Tdel)) = 1.3200
Enhancement (q) = 2.760
Enhancement (Del-T) = 2.141

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.453E+04	2.137E+04	1.118E+06	52.33	99.70
2	3.81	1.421E+04	2.170E+04	1.090E+06	50.22	99.78
3	3.28	1.387E+04	2.230E+04	1.071E+06	48.00	100.18
4	2.75	1.327E+04	2.261E+04	1.014E+06	44.85	99.80
5	2.22	1.251E+04	2.313E+04	9.541E+05	41.25	99.36
6	1.69	1.169E+04	2.469E+04	8.872E+05	35.94	100.11
7	1.16	1.042E+04	2.763E+04	7.833E+05	29.34	100.19
8	1.16	1.039E+04	2.747E+04	7.811E+05	29.44	100.14
9	1.69	1.164E+04	2.450E+04	8.855E+05	36.14	100.20
10	2.22	1.253E+04	2.357E+04	9.680E+05	41.07	100.01
11	2.75	1.363E+04	2.370E+04	1.047E+06	44.15	99.96
12	3.28	1.425E+04	2.330E+04	1.097E+06	47.09	99.96
13	3.81	1.501E+04	2.359E+04	1.151E+06	48.81	99.96
14	4.34	1.534E+04	2.312E+04	1.175E+06	50.83	99.80

Least-squares line for q = a*delta-T^b
a = 6.0304E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CU75A

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPALL
      Data taken by               : MEYER
      This analysis done on file : CUSA
      This analysis includes end-fin effect
      Thermal conductivity        = 390.8 (W/m.K)
      Inside diameter, Di         = 12.70 (mm)
      Outside diameter, Do        = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.7199
Alpha (based on Nussalt (Tdel)) =  1.7896
Enhancement (q)                  =  2.698
Enhancement (Del-T)              =  2.105
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	1.424E+04	2.145E+04	1.106E+06	51.55	100.00
2	3.31	1.402E+04	2.306E+04	1.079E+06	48.92	99.84
3	3.29	1.348E+04	2.221E+04	1.037E+06	46.59	99.86
4	2.75	1.239E+04	2.261E+04	9.397E+05	43.78	99.98
5	2.22	1.207E+04	2.294E+04	9.229E+05	40.22	99.97
6	1.69	1.120E+04	2.438E+04	8.486E+05	34.80	99.90
7	1.16	1.001E+04	2.737E+04	7.512E+05	25.95	100.03
8	1.16	9.364E+03	2.752E+04	7.491E+05	27.22	100.18
9	1.69	1.110E+04	2.393E+04	8.454E+05	35.33	100.16
10	2.22	1.214E+04	2.320E+04	9.262E+05	39.92	99.94
11	2.75	1.306E+04	2.310E+04	9.970E+05	43.17	99.75
12	3.29	1.372E+04	2.234E+04	1.054E+06	46.15	100.08
13	3.31	1.446E+04	2.307E+04	1.107E+06	47.99	100.21
14	4.34	1.431E+04	2.239E+04	1.142E+06	49.89	100.11

```
Least-squares line for q = a*delta-T^b
  a =  5.9425E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file CUSA

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPALL
      Data taken by              : MEYER
      This analysis done on file : CUSMTA
      This analysis includes end-fin effect
      Thermal conductivity     = 390.8 (W/m.K)
      Inside diameter, Di      = 12.70 (mm)
      Outside diameter, Do     = 14.38 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.4435
Alpha (based on Nusselt (Tdel)) =  0.9924
Enhancement (q)                   =  1.067
Enhancement (Del-T)               =  1.050
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	7.567E+03	9.622E+03	6.064E+05	63.02	99.90
2	3.83	7.586E+03	9.929E+03	6.049E+05	60.92	99.70
3	3.29	7.381E+03	9.939E+03	5.900E+05	59.37	99.93
4	2.76	7.309E+03	1.031E+04	5.821E+05	56.46	99.85
5	2.23	7.061E+03	1.055E+04	5.534E+05	53.05	99.77
6	1.70	6.655E+03	1.078E+04	5.269E+05	48.89	100.14
7	1.17	6.172E+03	1.164E+04	4.832E+05	41.51	100.05
8	1.17	6.174E+03	1.165E+04	4.839E+05	41.53	100.10
9	1.70	6.686E+03	1.086E+04	5.281E+05	48.64	99.98
10	2.23	7.093E+03	1.061E+04	5.617E+05	52.93	99.85
11	2.76	7.375E+03	1.043E+04	5.877E+05	56.34	100.20
12	3.29	7.574E+03	1.028E+04	6.046E+05	58.81	100.17
13	3.82	7.817E+03	1.031E+04	6.201E+05	60.15	100.00
14	4.35	7.358E+03	1.008E+04	6.242E+05	61.35	100.08

```
Least-Squares Line for Ho vs q curve:
  Slope      =  0.0000E+00
  Intercept  =  0.0000E+00

Least-squares line for q = a*delta-T^b
  a =  2.3429E+04
  b =  7.5000E-01
```

```
NOTE: Program name : DRPALL
      Data taken by                : MEYER
      This analysis done on file : AL15
      This analysis includes end-fin effect
      Thermal conductivity       = 231.8 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : ALUMINUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.3371
Alpha (based on Nusselt (Tdel)) =  1.5470
Enhancement (q)                  =  2.370
Enhancement (Del-T)              =  1.910
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	1.316E+04	2.117E+04	3.940E+05	18.62	48.88
2	3.83	1.264E+04	2.108E+04	3.757E+05	17.82	48.75
3	3.30	1.215E+04	2.136E+04	3.631E+05	17.00	48.82
4	2.77	1.156E+04	2.178E+04	3.439E+05	15.79	48.82
5	2.23	1.081E+04	2.239E+04	3.202E+05	14.30	48.71
6	1.70	9.760E+03	2.294E+04	2.878E+05	12.55	48.81
7	1.17	8.526E+03	2.571E+04	2.496E+05	9.71	48.93
8	1.17	8.501E+03	2.549E+04	2.496E+05	9.79	49.01
9	1.70	9.927E+03	2.333E+04	2.915E+05	12.49	48.99
10	2.23	1.081E+04	2.238E+04	3.201E+05	14.30	48.65
11	2.77	1.145E+04	2.140E+04	3.415E+05	15.96	48.79
12	3.30	1.207E+04	2.112E+04	3.613E+05	17.10	48.93
13	3.83	1.276E+04	2.140E+04	3.791E+05	17.71	48.89
14	4.36	1.312E+04	2.103E+04	3.985E+05	18.47	48.91

```
Least-squares line for q = a*delta-T^b
  a =  4.3701E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file AL15

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL125
This analysis includes end-fin effect
Thermal conductivity = 231.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4124
Alpha (based on Nusselt (Tdel)) = 1.3676
Enhancement (q) = 2.011
Enhancement (Del-T) = 1.688

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	1.191E+04	1.810E+04	3.605E+05	19.92	48.57
2	3.83	1.167E+04	1.849E+04	3.502E+05	18.95	48.53
3	3.30	1.108E+04	1.826E+04	3.359E+05	18.39	48.70
4	2.77	1.062E+04	1.865E+04	3.229E+05	17.31	48.84
5	2.23	9.837E+03	1.876E+04	2.984E+05	15.91	48.77
6	1.70	9.145E+03	1.981E+04	2.756E+05	13.91	48.80
7	1.17	8.066E+03	2.193E+04	2.391E+05	10.90	48.70
8	1.17	8.053E+03	2.183E+04	2.393E+05	10.96	48.75
9	1.70	9.145E+03	1.983E+04	2.764E+05	13.94	48.81
10	2.24	1.003E+04	1.923E+04	3.031E+05	15.72	48.57
11	2.77	1.066E+04	1.882E+04	3.223E+05	17.12	48.44
12	3.30	1.105E+04	1.821E+04	3.366E+05	18.60	48.79
13	3.83	1.162E+04	1.838E+04	3.498E+05	19.03	48.54
14	4.36	1.137E+04	1.822E+04	3.614E+05	19.94	48.67

Least-squares line for q = a*delta-T^b
a = 3.3395E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL125

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL1
This analysis includes end-fin effect
Thermal conductivity = 231.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5568
Alpha (based on Nusselt (Tdel)) = 1.4014
Enhancement (q) = 2.077
Enhancement (Del-T) = 1.730

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.278E+04	1.931E+04	3.470E+05	17.97	48.83
2	3.81	1.236E+04	1.933E+04	3.344E+05	17.30	48.90
3	3.28	1.196E+04	1.963E+04	3.244E+05	16.52	48.90
4	2.75	1.143E+04	1.995E+04	3.082E+05	15.45	48.83
5	2.22	1.069E+04	2.017E+04	2.886E+05	14.31	48.88
6	1.69	9.554E+03	2.020E+04	2.583E+05	12.81	48.87
7	1.16	8.564E+03	2.307E+04	2.310E+05	10.01	48.93
8	1.16	8.711E+03	2.340E+04	2.324E+05	9.93	48.94
9	1.69	9.802E+03	2.031E+04	2.648E+05	12.67	48.85
10	2.22	1.067E+04	2.013E+04	2.870E+05	14.25	48.60
11	2.75	1.135E+04	1.974E+04	3.069E+05	15.55	48.63
12	3.28	1.199E+04	1.973E+04	3.256E+05	16.50	48.70
13	3.81	1.237E+04	1.937E+04	3.348E+05	17.23	48.80
14	4.34	1.271E+04	1.915E+04	3.448E+05	18.01	48.93

Least-squares line for q = a*delta-T^b
a = 3.9621E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL75
This analysis includes end-fin effect
Thermal conductivity = 231.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5685
Alpha (based on Nusselt (Tdel)) = 1.3332
Enhancement (q) = 1.343
Enhancement (Del-T) = 1.646

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tof (C)	Ts (C)
1	4.37	1.183E+04	1.744E+04	3.626E+05	20.79	48.79
2	3.83	1.163E+04	1.784E+04	3.526E+05	19.76	48.68
3	3.30	1.111E+04	1.773E+04	3.398E+05	19.16	48.82
4	2.77	1.069E+04	1.811E+04	3.247E+05	17.93	48.75
5	2.24	1.009E+04	1.854E+04	3.043E+05	16.41	48.61
6	1.70	9.327E+03	1.937E+04	2.798E+05	14.44	48.60
7	1.17	8.148E+03	2.052E+04	2.449E+05	11.94	49.01
8	1.17	8.134E+03	2.083E+04	2.458E+05	11.80	48.92
9	1.70	9.275E+03	1.917E+04	2.796E+05	14.58	48.63
10	2.24	9.978E+03	1.818E+04	3.033E+05	16.68	48.66
11	2.77	1.061E+04	1.791E+04	3.218E+05	17.97	48.45
12	3.30	1.098E+04	1.740E+04	3.351E+05	19.26	48.57
13	3.83	1.152E+04	1.759E+04	3.483E+05	19.79	48.53
14	4.37	1.174E+04	1.725E+04	3.555E+05	20.61	48.60

Least-squares line for q = a*delta-T^b
a = 3.7313E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL75

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL5
This analysis includes end-fin effect
Thermal conductivity = 231.9 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7317
Alpha (based on Nusselt (Tdel)) = 1.0320
Enhancement (q) = 1.381
Enhancement (Del-T) = 1.274

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	9.880E+03	1.326E+04	3.043E+05	22.98	48.77
2	3.83	9.551E+03	1.311E+04	2.924E+05	22.30	48.69
3	3.30	9.318E+03	1.325E+04	2.870E+05	21.66	48.70
4	2.77	8.990E+03	1.336E+04	2.762E+05	20.57	48.68
5	2.24	8.536E+03	1.346E+04	2.615E+05	19.43	48.64
6	1.70	7.991E+03	1.382E+04	2.435E+05	17.62	48.56
7	1.17	7.325E+03	1.509E+04	2.217E+05	14.69	48.67
8	1.17	7.316E+03	1.505E+04	2.218E+05	14.74	43.72
9	1.70	8.039E+03	1.398E+04	2.481E+05	17.75	48.81
10	2.24	8.546E+03	1.350E+04	2.644E+05	19.58	48.70
11	2.77	8.897E+03	1.318E+04	2.783E+05	21.12	48.91
12	3.30	9.237E+03	1.311E+04	2.891E+05	22.06	43.38
13	3.84	9.417E+03	1.237E+04	2.933E+05	22.73	43.99
14	4.37	9.605E+03	1.278E+04	2.983E+05	23.39	48.96

Least-squares line for q = a*delta-T^b
a = 2.8531E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL5

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPALL
      Data taken by              : MEYER
      This analysis done on file : ALSMT
      This analysis includes end-fin effect
      Thermal conductivity      = 231.8 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : SMOOTH TUBE
      Tube material      : ALUMINUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.3380
Alpha (based on Nusselt (Tdel)) =  0.3188
Enhancement (q)                   =  1.015
Enhancement (Dal-T)               =  1.011
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	7.842E+03	9.533E+03	2.432E+05	25.11	48.83
2	3.33	7.899E+03	1.001E+04	2.430E+05	24.23	48.63
3	3.30	7.712E+03	1.002E+04	2.380E+05	23.75	48.66
4	2.77	7.561E+03	1.037E+04	2.350E+05	22.66	48.54
5	2.24	7.312E+03	1.035E+04	2.243E+05	21.72	48.70
6	1.70	7.029E+03	1.076E+04	2.1[illegible]7E+05	19.86	48.50
7	1.17	6.446E+03	1.117E+04	1.345E+05	17.40	48.62
8	1.17	6.466E+03	1.123E+04	1.355E+05	17.40	48.67
9	1.70	6.969E+03	1.063E+04	2.148E+05	20.22	48.37
10	2.24	7.341E+03	1.041E+04	2.279E+05	21.89	48.91
11	2.77	7.716E+03	1.048E+04	2.395E+05	22.85	48.78
12	3.30	7.890E+03	1.033E+04	2.447E+05	23.59	48.64
13	3.84	7.901E+03	1.001E+04	2.436E+05	24.32	48.64
14	4.37	8.032E+03	9.375E+03	2.486E+05	24.92	48.73

```
Least-Squares Line for Ho vs q curve:
  Slope      =  0.0000E+00
  Intercept  =  0.0000E+00

Least-squares line for q = a*delta-T^b
  a =  2.2480E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file ALSMT

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPALL
      Data taken by              : MEYER
      This analysis done on file : ALISA
      This analysis includes end-fin effect
      Thermal conductivity      = 231.8 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : RECTANGULAR FINNED TUBE
      Tube material      : ALUMINUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.6387
Alpha (based on Nusselt (Tdel)) =  1.3023
Enhancement (q)                  =  2.327
Enhancement (Del-T)              =  2.238
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.33	1.494E+04	2.398E+04	1.133E+06	47.29	100.06
2	3.80	1.457E+04	2.445E+04	1.099E+06	44.93	100.04
3	3.28	1.406E+04	2.493E+04	1.060E+06	42.52	100.12
4	2.75	1.341E+04	2.544E+04	1.006E+06	39.54	100.16
5	2.22	1.246E+04	2.577E+04	9.314E+05	36.14	100.10
6	1.69	1.133E+04	2.671E+04	8.396E+05	31.43	99.96
7	1.16	9.958E+03	3.023E+04	7.334E+05	24.27	100.24
8	1.16	9.946E+03	3.011E+04	7.325E+05	24.33	100.25
9	1.69	1.129E+04	2.656E+04	8.404E+05	31.65	100.08
10	2.22	1.244E+04	2.571E+04	9.300E+05	36.18	99.92
11	2.75	1.327E+04	2.499E+04	9.938E+05	39.76	99.87
12	3.27	1.393E+04	2.449E+04	1.045E+06	42.67	99.90
13	3.80	1.466E+04	2.461E+04	1.095E+06	44.49	99.92
14	4.33	1.505E+04	2.413E+04	1.120E+06	46.42	99.90

```
Least-squares line for q = a*delta-T^b
  a =  6.3638E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file ALISA

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL12SA
This analysis includes end-fin effect
Thermal conductivity = 231.8 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5237
Alpha (based on Nusselt (Tdel)) = 1.6663
Enhancement (q) = 2.453
Enhancement (Del-T) = 1.960

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.323E+04	2.047E+04	1.022E+06	49.93	100.10
2	3.81	1.283E+04	2.059E+04	9.855E+05	47.87	100.00
3	3.23	1.240E+04	2.078E+04	9.493E+05	45.67	100.03
4	2.75	1.190E+04	2.130E+04	9.106E+05	42.75	100.13
5	2.22	1.126E+04	2.215E+04	8.551E+05	38.60	99.65
6	1.69	1.027E+04	2.285E+04	7.784E+05	34.07	99.92
7	1.16	9.039E+03	2.529E+04	6.810E+05	26.93	100.14
8	1.16	9.048E+03	2.538E+04	6.828E+05	26.90	100.21
9	1.69	1.036E+04	2.339E+04	7.907E+05	33.90	100.08
10	2.22	1.129E+04	2.235E+04	8.659E+05	38.75	99.92
11	2.75	1.196E+04	2.159E+04	9.237E+05	42.79	100.23
12	3.23	1.259E+04	2.139E+04	9.731E+05	45.50	100.17
13	3.81	1.301E+04	2.096E+04	1.004E+06	47.90	100.14
14	4.34	1.344E+04	2.085E+04	1.036E+06	49.68	100.17

Least-squares line for q = a*delta-T^b
a = 5.5439E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL12SA

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : AL1A
This analysis includes end-fin effect
Thermal conductivity = 231.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.38 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : ALUMINUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7035
Alpha (based on Nusselt (Tdel)) = 1.8205
Enhancement (q) = 2.761
Enhancement (Del-T) = 2.142

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	1.468E+04	2.293E+04	1.083E+06	47.42	100.18
2	3.79	1.445E+04	2.352E+04	1.055E+06	44.88	99.98
3	3.26	1.392E+04	2.376E+04	1.012E+06	42.61	100.01
4	2.74	1.327E+04	2.411E+04	9.615E+05	39.88	100.09
5	2.21	1.242E+04	2.449E+04	8.957E+05	36.57	100.20
6	1.68	1.138E+04	2.553E+04	8.153E+05	31.93	100.09
7	1.16	1.006E+04	2.867E+04	7.139E+05	24.90	100.15
8	1.16	1.004E+04	2.850E+04	7.110E+05	24.95	99.99
9	1.68	1.136E+04	2.543E+04	8.152E+05	32.06	100.14
10	2.21	1.242E+04	2.453E+04	8.963E+05	36.56	100.09
11	2.73	1.322E+04	2.391E+04	9.518E+05	39.80	99.95
12	3.26	1.405E+04	2.403E+04	1.012E+06	42.12	100.05
13	3.78	1.445E+04	2.339E+04	1.041E+06	44.51	100.20
14	4.31	1.488E+04	2.312E+04	1.066E+06	46.10	100.04

Least-squares line for q = a*delta-T^b
a = 6.0952E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file AL1A

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
      Data taken by   : MEYER
      This analysis done on file : AL75A
      This analysis includes end-fin effect
      Thermal conductivity   = 231.8 (W/m.K)
      Inside diameter, Di   = 12.70 (mm)
      Outside diameter, Do   = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : RECTANGULAR FINNED TUBE
      Tube material   : ALUMINUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 2.8750
Alpha (based on Nusselt (Tdel)) = 1.4894
Enhancement (q)   = 2.112
Enhancement (Del-T)   = 1.752

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.235E+04	1.749E+04	9.531E+05	54.84	99.91
2	3.81	1.217E+04	1.783E+04	9.412E+05	52.79	100.02
3	3.28	1.189E+04	1.821E+04	9.179E+05	50.41	99.98
4	2.75	1.140E+04	1.836E+04	8.801E+05	47.33	100.17
5	2.22	1.085E+04	1.879E+04	8.231E+05	44.12	99.78
6	1.69	1.011E+04	1.960E+04	7.721E+05	39.39	99.92
7	1.16	9.103E+03	2.150E+04	6.888E+05	32.04	100.06
8	1.15	9.092E+03	2.145E+04	6.892E+05	32.13	100.16
9	1.69	1.006E+04	1.945E+04	7.694E+05	39.57	99.83
10	2.22	1.093E+04	1.910E+04	8.428E+05	44.14	100.05
11	2.75	1.163E+04	1.897E+04	8.952E+05	47.18	99.91
12	3.28	1.185E+04	1.811E+04	9.149E+05	50.53	99.99
13	3.81	1.229E+04	1.807E+04	9.484E+05	52.48	100.11
14	4.34	1.255E+04	1.786E+04	9.689E+05	54.25	100.01

Least-squares line for q = a*delta-T^b
  a = 4.8943E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file AL75A

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : ORPALL
      Data taken by               : MEYER
      This analysis done on file : ALSA
      This analysis includes end-fin affect
      Thermal conductivity       = 231.8 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : ALUMINUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.9440
Alpha (based on Nusselt (Tdel)) =  1.1082
Enhancement (q)                 =  1.424
Enhancement (Del-T)             =  1.304
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	9.744E+03	1.266E+04	7.745E+05	61.13	100.04
2	3.82	9.537E+03	1.278E+04	7.537E+05	59.45	100.06
3	3.29	9.372E+03	1.287E+04	7.389E+05	57.41	99.79
4	2.76	9.160E+03	1.314E+04	7.201E+05	54.81	99.80
5	2.23	8.756E+03	1.325E+04	6.857E+05	51.73	99.79
6	1.70	8.227E+03	1.352E+04	6.429E+05	47.57	99.36
7	1.17	7.697E+03	1.493E+04	5.942E+05	39.73	99.81
8	1.17	7.690E+03	1.490E+04	5.939E+05	39.84	99.34
9	1.70	8.282E+03	1.368E+04	6.486E+05	47.42	99.39
10	2.23	8.696E+03	1.313E+04	6.864E+05	52.27	100.17
11	2.76	9.161E+03	1.315E+04	7.241E+05	55.07	100.05
12	3.29	9.257E+03	1.268E+04	7.347E+05	57.95	100.14
13	3.82	9.605E+03	1.279E+04	7.590E+05	59.35	100.08
14	4.35	9.862E+03	1.251E+04	7.648E+05	61.15	100.18

```
Least-squares line for q = a*delta-T^b
  a =  3.5743E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file ALSA

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPALL
      Data taken by                : MEYER
      This analysis done on file : ALSMTA
      This analysis includes end-fin effect
      Thermal conductivity        = 231.8 (W/m.K)
      Inside diameter, Di         = 12.70 (mm)
      Outside diameter, Do        = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : ALUMINUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.9761
Alpha (based on Nusselt (Tdel)) =  0.8561
Enhancement (q)                   =  1.010
Enhancement (Del-T)               =  1.007
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	7.538E+03	9.153E+03	6.012E+05	65.64	99.93
2	3.82	7.628E+03	9.499E+03	6.058E+05	63.78	99.83
3	3.29	7.555E+03	9.663E+03	6.004E+05	62.13	99.85
4	2.76	7.348E+03	9.632E+03	5.841E+05	60.25	100.02
5	2.23	7.223E+03	1.002E+04	5.720E+05	57.10	100.00
6	1.70	6.886E+03	1.022E+04	5.418E+05	53.01	99.87
7	1.17	6.421E+03	1.075E+04	5.008E+05	46.58	99.92
8	1.17	6.413E+03	1.073E+04	5.009E+05	46.69	100.05
9	1.70	6.886E+03	1.022E+04	5.417E+05	53.00	99.85
10	2.23	7.156E+03	9.889E+03	5.685E+05	57.49	100.27
11	2.76	7.427E+03	9.829E+03	5.904E+05	60.07	100.10
12	3.29	7.583E+03	9.706E+03	6.030E+05	62.12	99.99
13	3.82	7.668E+03	9.556E+03	6.082E+05	63.64	99.95
14	4.35	7.634E+03	9.386E+03	6.106E+05	65.05	99.99

```
Least-Squares Line for Ho vs q curve:
  Slope      =  0.0000E+00
  Intercept  =  0.0000E+00

Least-squares line for q = a*delta-T^b
  a =  2.7235E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file ALSMTA

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
      Data taken by : MEYER
      This analysis done on file : CN15
      This analysis includes end-fin effect
      Thermal conductivity = 55.3 (W/m.K)
      Inside diameter, Di = 12.70 (mm)
      Outside diameter, Do = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement : RECTANGULAR FINNED TUBE
      Tube material : 90/10 CU/NI
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4413
Alpha (based on Nusselt (Tdel)) = 1.1136
Enhancement (q) = 1.538
Enhancement (Del-T) = 1.381

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	9.491E+03	1.473E+04	2.869E+05	19.48	48.59
2	3.83	9.186E+03	1.462E+04	2.754E+05	18.84	48.50
3	3.30	8.982E+03	1.495E+04	2.707E+05	18.11	48.49
4	2.77	8.672E+03	1.523E+04	2.614E+05	17.16	48.56
5	2.23	8.234E+03	1.554E+04	2.477E+05	15.94	48.61
6	1.70	7.638E+03	1.603E+04	2.296E+05	14.32	48.74
7	1.17	6.830E+03	1.739E+04	2.037E+05	11.71	48.83
8	1.17	6.835E+03	1.742E+04	2.040E+05	11.71	48.86
9	1.70	7.706E+03	1.634E+04	2.329E+05	14.24	48.83
10	2.23	8.289E+03	1.575E+04	2.512E+05	15.95	48.73
11	2.77	8.754E+03	1.550E+04	2.662E+05	17.18	48.59
12	3.30	9.160E+03	1.545E+04	2.792E+05	18.07	48.73
13	3.83	9.510E+03	1.546E+04	2.881E+05	18.64	48.80
14	4.36	9.520E+03	1.479E+04	2.894E+05	19.56	48.37

Least-squares line for q = a*delta-T^b
  a = 3.1405E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file CN15

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CN1
This analysis includes end-fin effect
Thermal conductivity = 55.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : 90/10 CU/NI
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6782
Alpha (based on Nusselt (Tdel)) = 1.0565
Enhancement (q) = 1.425
Enhancement (Del-T) = 1.304

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	9.103E+03	1.336E+04	2.654E+05	19.86	48.45
2	3.83	8.958E+03	1.352E+04	2.603E+05	19.25	48.47
3	3.29	8.951E+03	1.419E+04	2.615E+05	18.44	48.54
4	2.76	8.641E+03	1.433E+04	2.512E+05	17.53	48.48
5	2.23	8.306E+03	1.477E+04	2.409E+05	16.31	48.45
6	1.70	7.801E+03	1.536E+04	2.262E+05	14.73	48.50
7	1.17	6.945E+03	1.601E+04	1.987E+05	12.41	48.54
8	1.17	6.923E+03	1.592E+04	1.980E+05	12.44	48.51
9	1.70	7.743E+03	1.515E+04	2.247E+05	14.83	48.52
10	2.23	8.338E+03	1.488E+04	2.432E+05	16.34	48.48
11	2.76	8.700E+03	1.451E+04	2.546E+05	17.55	48.48
12	3.30	9.090E+03	1.455E+04	2.676E+05	18.39	48.58
13	3.83	9.230E+03	1.427E+04	2.722E+05	19.07	48.62
14	4.36	9.515E+03	1.426E+04	2.737E+05	19.62	48.63

Least-squares line for q = a*delta-T^b
a = 2.3588E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CN1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CN7SR
This analysis includes end-fin effect
Thermal conductivity = 55.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : 90/10 CU/NI
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7136
Alpha (based on Nusselt (Tdel)) = 1.0377
Enhancement (q) = 1.331
Enhancement (Del-T) = 1.231

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	8.886E+03	1.239E+04	2.745E+05	21.23	48.47
2	3.84	8.789E+03	1.314E+04	2.724E+05	20.73	48.74
3	3.30	8.659E+03	1.346E+04	2.649E+05	19.68	48.54
4	2.77	8.385E+03	1.365E+04	2.579E+05	18.90	48.56
5	2.24	8.076E+03	1.406E+04	2.491E+05	17.72	48.78
6	1.70	7.673E+03	1.486E+04	2.341E+05	15.75	48.64
7	1.17	6.786E+03	1.517E+04	2.058E+05	13.56	48.81
8	1.17	6.805E+03	1.527E+04	2.064E+05	13.52	48.82
9	1.70	7.689E+03	1.492E+04	2.338E+05	15.67	48.54
10	2.24	8.171E+03	1.435E+04	2.507E+05	17.47	48.59
11	2.77	8.558E+03	1.411E+04	2.611E+05	18.51	48.37
12	3.30	8.856E+03	1.394E+04	2.724E+05	19.54	48.75
13	3.83	9.137E+03	1.393E+04	2.830E+05	20.32	48.96
14	4.37	9.156E+03	1.346E+04	2.827E+05	21.01	48.80

Least-squares line for q = a*delta-T^b
a = 2.8348E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CN7SR

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : ORPALL
      Data taken by              : MEYER
      This analysis done on file : CNS
      This analysis includes end-fin effect
      Thermal conductivity       =  55.3 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : 90/10 CU/NI
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.7548
Alpha (based on Nusselt (Tdel)) =  0.3487
Enhancement (q)                  =  1.235
Enhancement (Del-T)              =  1.171
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	8.436E+03	1.194E+04	2.659E+05	22.28	48.72
2	3.84	8.346E+03	1.214E+04	2.635E+05	21.70	48.94
3	3.30	8.188E+03	1.232E+04	2.582E+05	20.96	48.01
4	2.77	7.968E+03	1.253E+04	2.496E+05	19.92	48.58
5	2.24	7.562E+03	1.280E+04	2.387E+05	18.65	48.60
6	1.70	7.173E+03	1.305E+04	2.220E+05	17.01	48.52
7	1.17	6.438E+03	1.372E+04	2.006E+05	14.63	48.76
8	1.17	6.526E+03	1.384E+04	2.008E+05	14.50	48.64
9	1.70	7.081E+03	1.274E+04	2.209E+05	17.34	48.65
10	2.24	7.601E+03	1.264E+04	2.393E+05	18.93	48.73
11	2.77	7.926E+03	1.244E+04	2.483E+05	20.01	48.50
12	3.31	8.253E+03	1.249E+04	2.571E+05	20.59	48.43
13	3.84	8.281E+03	1.201E+04	2.537E+05	21.63	48.62
14	4.37	8.377E+03	1.182E+04	2.643E+05	22.36	48.82

```
Least-squares line for q = a*delta-T^b
  a =  2.6338E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file CNS

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
      Data taken by   : MEYER
      This analysis done on file : CN15A
      This analysis includes end-fin effect
      Thermal conductivity   = 55.3 (W/m.K)
      Inside diameter, Di   = 12.70 (mm)
      Outside diameter, Do   = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : RECTANGULAR FINNED TUBE
      Tube material   : 90/10 CU/NI
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)   = 3.1874
Alpha (based on Nusselt (Tdel)) = 1.5529
Enhancement (q)   = 2.233
Enhancement (Del-T)   = 1.927

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.34	1.183E+04	1.855E+04	9.212E+05	49.65	100.15
2	3.81	1.167E+04	1.890E+04	9.014E+05	47.68	99.91
3	3.28	1.148E+04	1.941E+04	8.823E+05	45.46	99.74
4	2.75	1.112E+04	1.979E+04	8.563E+05	43.23	100.21
5	2.22	1.064E+04	2.033E+04	8.122E+05	39.96	99.83
6	1.69	1.004E+04	2.149E+04	7.618E+05	35.45	99.88
7	1.16	9.009E+03	2.306E+04	6.791E+05	29.44	100.23
8	1.16	8.962E+03	2.277E+04	6.761E+05	29.69	100.26
9	1.69	9.915E+03	2.093E+04	7.551E+05	36.08	100.08
10	2.22	1.071E+04	2.059E+04	8.235E+05	39.99	100.24
11	2.75	1.131E+04	2.042E+04	8.717E+05	42.69	100.14
12	3.28	1.181E+04	2.036E+04	9.109E+05	44.75	100.20
13	3.81	1.217E+04	2.021E+04	9.367E+05	46.34	100.17
14	4.34	1.235E+04	1.979E+04	9.511E+05	48.06	100.22

Least-squares line for q = a*delta-T^b
  a = 5.1647E+04
  b = 7.5000E-01

NOTE: 14 data points were stored in file CN15A

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : CN1A
This analysis includes end-fin effect
Thermal conductivity = 55.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Patukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : 90/10 CU/NI
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8639
Alpha (based on Nusselt (Tdel)) = 1.3720
Enhancement (q) = 1.893
Enhancement (Del-T) = 1.614

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	1.0662E+04	1.640E+04	8.314E+05	50.70	100.04
2	3.81	1.0532E+04	1.689E+04	8.208E+05	48.50	99.98
3	3.28	1.0388E+04	1.727E+04	8.013E+05	46.44	99.92
4	2.75	1.0025E+04	1.750E+04	7.725E+05	44.15	100.09
5	2.22	9.5368E+03	1.776E+04	7.239E+05	41.09	99.95
6	1.69	9.0408E+03	1.831E+04	6.854E+05	36.24	99.75
7	1.16	8.0655E+03	1.999E+04	6.068E+05	30.35	100.03
8	1.16	8.0525E+03	1.992E+04	6.065E+05	30.45	100.09
9	1.69	8.3408E+03	1.847E+04	6.794E+05	36.78	100.00
10	2.22	9.6366E+03	1.807E+04	7.355E+05	40.70	100.09
11	2.75	1.0178E+04	1.788E+04	7.772E+05	43.46	100.08
12	3.28	1.0548E+04	1.764E+04	8.040E+05	45.57	99.89
13	3.81	1.0772E+04	1.728E+04	8.215E+05	47.53	99.99
14	4.33	1.0966E+04	1.702E+04	8.367E+05	49.17	100.16

Least-squares line for q = a*delta-T^b
a = 4.5488E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file CN1A

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPALL
      Data taken by                  : MEYER
      This analysis done on file : CN75AR
      This analysis includes end-fin effect
      Thermal conductivity       =  55.3 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : 90/10 CU/NI
      Pressure condition : ATMOSPHERIC
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.9431
Alpha (based on Nussalt (Tdel)) =  1.2931
Enhancement (q)                  =  1.750
Enhancement (Del-T)              =  1.521
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	1.036E+04	1.561E+04	8.167E+05	52.32	99.99
2	3.82	1.020E+04	1.581E+04	7.989E+05	50.52	99.83
3	3.29	1.014E+04	1.645E+04	7.866E+05	47.81	99.55
4	2.76	9.537E+03	1.610E+04	7.497E+05	46.57	100.03
5	2.23	9.271E+03	1.669E+04	7.232E+05	43.32	100.24
6	1.69	8.607E+03	1.690E+04	6.659E+05	39.41	100.12
7	1.16	7.867E+03	1.848E+04	6.027E+05	32.61	100.13
8	1.16	7.891E+03	1.863E+04	6.049E+05	32.48	100.14
9	1.70	8.632E+03	1.700E+04	6.687E+05	39.33	100.18
10	2.23	9.243E+03	1.660E+04	7.185E+05	43.23	99.99
11	2.76	9.667E+03	1.629E+04	7.532E+05	46.25	99.96
12	3.29	1.009E+04	1.630E+04	7.836E+05	48.08	99.97
13	3.81	1.017E+04	1.571E+04	7.925E+05	50.46	100.08
14	4.34	1.029E+04	1.541E+04	7.996E+05	51.90	99.80

```
Least-squares line for q = a*delta-T^b
  a =  4.2536E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file CN75AR

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPALL
      Data taken by              : MEYER
      This analysis done on file : CNSA
      This analysis includes end-fin effect
      Thermal conductivity       =  55.3 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
    - This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : 90/10 CU/NI
      Pressure condition  : ATMOSPHERIC
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov)       =  2.9430
Alpha (based on Nussalt (Tdel))    =  1.1257
Enhancement (q)                    =  1.454
Enhancement (Del-T)                =  1.324
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	9.000E+03	1.278E+04	7.289E+05	57.02	99.98
2	3.83	8.925E+03	1.303E+04	7.132E+05	55.18	99.87
3	3.30	8.781E+03	1.326E+04	7.031E+05	53.03	99.68
4	2.77	8.495E+03	1.334E+04	6.806E+05	51.03	99.81
5	2.23	8.232E+03	1.374E+04	6.567E+05	47.78	99.93
6	1.70	7.823E+03	1.431E+04	6.214E+05	43.43	100.05
7	1.17	7.233E+03	1.562E+04	5.683E+05	36.39	100.05
8	1.17	7.225E+03	1.558E+04	5.681E+05	36.47	100.10
9	1.70	7.873E+03	1.447E+04	6.234E+05	43.09	99.90
10	2.23	8.315E+03	1.396E+04	6.629E+05	47.48	100.02
11	2.76	8.689E+03	1.380E+04	6.960E+05	50.44	100.17
12	3.29	9.170E+03	1.413E+04	7.310E+05	51.75	100.06
13	3.82	9.294E+03	1.379E+04	7.390E+05	53.59	99.84
14	4.36	9.477E+03	1.371E+04	7.522E+05	54.85	99.74

```
Least-squares line for q = a*delta-T^b
  a =  3.6742E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file CNSA

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : SS15
This analysis includes end-fin affect
Thermal conductivity = 14.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : STAINLESS-STEEL
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.3481
Alpha (based on Nusselt (Tdel)) = 0.7755
Enhancement (q) = .944
Enhancement (Del-T) = .957

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	5.848E+03	1.062E+04	1.853E+05	17.45	48.74
2	3.84	5.758E+03	1.076E+04	1.816E+05	16.88	48.71
3	3.30	5.658E+03	1.098E+04	1.771E+05	16.13	48.63
4	2.77	5.417E+03	1.086E+04	1.716E+05	15.79	48.80
5	2.24	5.200E+03	1.110E+04	1.640E+05	14.77	48.63
6	1.70	4.857E+03	1.125E+04	1.523E+05	13.57	48.75
7	1.17	4.441E+03	1.227E+04	1.393E+05	11.41	49.04
8	1.17	4.458E+03	1.238E+04	1.402E+05	11.32	49.00
9	1.70	4.853E+03	1.128E+04	1.536E+05	13.62	48.82
10	2.24	5.134E+03	1.081E+04	1.644E+05	15.21	49.05
11	2.77	5.421E+03	1.083E+04	1.723E+05	15.81	48.89
12	3.31	5.638E+03	1.091E+04	1.778E+05	16.23	48.66
13	3.84	5.805E+03	1.093E+04	1.830E+05	16.75	48.90
14	4.37	5.897E+03	1.073E+04	1.883E+05	17.46	48.98

Least-squares line for q = a*delta-T^b
a = 2.1300E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file SS15

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : SS1
This analysis includes end-fin effect
Thermal conductivity = 14.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : STAINLESS-STEEL
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.1992
Alpha (based on Nusselt (Tdel)) = 0.7816
Enhancement (q) = .954
Enhancement (Del-T) = .965

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tcf (C)	Ts (C)
1	4.36	6.135E+03	1.104E+04	1.828E+05	16.55	48.91
2	3.83	5.960E+03	1.087E+04	1.766E+05	16.25	48.86
3	3.30	5.904E+03	1.122E+04	1.754E+05	15.64	48.74
4	2.76	5.689E+03	1.115E+04	1.689E+05	15.15	48.79
5	2.23	5.470E+03	1.132E+04	1.631E+05	14.40	48.93
6	1.70	5.155E+03	1.156E+04	1.532E+05	13.25	48.93
7	1.17	4.718E+03	1.229E+04	1.393E+05	11.33	48.94
8	1.17	4.722E+03	1.232E+04	1.394E+05	11.31	48.93
9	1.70	5.143E+03	1.151E+04	1.533E+05	13.32	48.89
10	2.23	5.452E+03	1.126E+04	1.629E+05	14.47	48.79
11	2.76	5.712E+03	1.126E+04	1.709E+05	15.18	48.75
12	3.30	5.819E+03	1.093E+04	1.744E+05	15.96	48.70
13	3.83	6.010E+03	1.105E+04	1.788E+05	16.19	48.71
14	4.36	6.054E+03	1.078E+04	1.802E+05	16.71	48.74

Least-squares line for q = a*delta-T^b
a = 2.2115E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file SS1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPALL
      Data taken by                : MEYER
      This analysis done on file : SS75
      This analysis includes end-fin effect
      Thermal conductivity       =  14.3 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement   : RECTANGULAR FINNED TUBE
      Tube material      : STAINLESS-STEEL
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)       =  2.5815
Alpha (based on Nusselt (Tdel)) =  0.3054
Enhancement (q)                     =  1.160
Enhancement (Del-T)                 =  1.118
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	6.803E+03	1.275E+04	2.124E+05	16.65	48.44
2	3.84	6.657E+03	1.270E+04	2.090E+05	16.46	48.82
3	3.30	6.568E+03	1.300E+04	2.062E+05	15.86	48.72
4	2.77	6.440E+03	1.335E+04	1.939E+05	14.97	48.48
5	2.24	6.086E+03	1.304E+04	1.888E+05	14.48	48.56
6	1.70	5.732E+03	1.323E+04	1.762E+05	13.32	48.45
7	1.17	5.259E+03	1.402E+04	1.617E+05	11.53	48.73
8	1.17	5.283E+03	1.424E+04	1.513E+05	11.37	48.60
9	1.70	5.774E+03	1.346E+04	1.794E+05	13.33	48.72
10	2.24	6.036E+03	1.309E+04	1.886E+05	14.41	48.46
11	2.77	6.364E+03	1.303E+04	1.376E+05	15.16	48.48
12	3.30	6.446E+03	1.253E+04	2.013E+05	16.12	48.66
13	3.84	6.519E+03	1.220E+04	2.047E+05	16.78	48.93
14	4.37	6.717E+03	1.244E+04	2.085E+05	16.76	48.61

```
Least-squares line for q = a*delta-T^b
  a =  2.5577E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file SS75

NOTE: 14 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPALL
      Data taken by               : MEYER
      This analysis done on file : SSS
      This analysis includes end-fin effect
      Thermal conductivity        =  14.3 (W/m.K)
      Inside diameter, Di         = 12.70 (mm)
      Outside diameter, Do        = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : STAINLESS-STEEL
      Pressure condition : VACUUM
      Nussalt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.3359
Alpha (based on Nussalt (Tdel)) =  0.3679
Enhancement (q)                   =  1.268
Enhancement (Del-T)               =  1.195
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.37	7.084E+03	1.427E+04	2.153E+05	15.09	48.26
2	3.83	6.785E+03	1.368E+04	2.065E+05	15.10	48.35
3	3.30	6.718E+03	1.420E+04	2.062E+05	14.52	48.70
4	2.77	6.432E+03	1.402E+04	1.994E+05	14.22	48.74
5	2.24	6.185E+03	1.439E+04	1.901E+05	13.21	48.48
6	1.70	5.790E+03	1.467E+04	1.787E+05	12.18	48.71
7	1.17	5.215E+03	1.535E+04	1.596E+05	10.40	48.74
8	1.17	5.255E+03	1.579E+04	1.603E+05	10.15	48.58
9	1.70	5.813E+03	1.484E+04	1.800E+05	12.13	48.63
10	2.24	6.196E+03	1.447E+04	1.916E+05	13.24	48.43
11	2.77	6.485E+03	1.431E+04	2.006E+05	14.02	48.30
12	3.30	6.573E+03	1.361E+04	2.065E+05	15.17	48.71
13	3.84	6.731E+03	1.340E+04	2.107E+05	15.63	48.80
14	4.37	6.922E+03	1.364E+04	2.157E+05	15.81	48.60

```
Least-squares line for q = a*delta-T^b
  a =  2.7460E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file SSS

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : SS15A
This analysis includes end-fin effect
Thermal conductivity = 14.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : STAINLESS-STEEL
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4846
Alpha (based on Nusselt (Tdel)) = 0.9363
Enhancement (q) = 1.138
Enhancement (Del-T) = 1.102

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	6.562E+03	1.200E+04	5.307E+05	44.24	100.07
2	3.83	6.468E+03	1.210E+04	5.214E+05	43.08	100.04
3	3.30	6.401E+03	1.243E+04	5.129E+05	41.27	99.83
4	2.76	6.163E+03	1.230E+04	4.939E+05	40.14	99.75
5	2.23	5.939E+03	1.248E+04	4.754E+05	38.10	99.36
6	1.70	5.610E+03	1.270E+04	4.434E+05	35.37	100.23
7	1.17	5.211E+03	1.382E+04	4.123E+05	29.83	99.83
8	1.17	5.228E+03	1.395E+04	4.130E+05	29.62	99.63
9	1.70	5.538E+03	1.256E+04	4.471E+05	35.32	99.37
10	2.23	5.917E+03	1.240E+04	4.744E+05	38.26	99.32
11	2.76	6.235E+03	1.259E+04	4.999E+05	39.69	99.74
12	3.29	6.370E+03	1.231E+04	5.109E+05	41.51	99.96
13	3.83	6.505E+03	1.222E+04	5.229E+05	42.78	100.05
14	4.36	6.602E+03	1.212E+04	5.317E+05	43.88	100.13

Least-squares line for q = a*delta-T^b
a = 3.1299E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file SS15A

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : SS12SA
This analysis includes end-fin effect
Thermal conductivity = 14.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : STAINLESS-STEEL
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8836
Alpha (based on Nusselt (Tdel)) = 0.9911
Enhancement (q) = 1.227
Enhancement (Del-T) = 1.166

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.36	6.794E+03	1.225E+04	5.513E+05	45.01	100.00
2	3.83	6.755E+03	1.250E+04	5.471E+05	43.76	100.16
3	3.30	6.663E+03	1.271E+04	5.366E+05	42.23	99.79
4	2.77	6.525E+03	1.291E+04	5.243E+05	40.60	99.81
5	2.23	6.306E+03	1.308E+04	5.056E+05	38.66	99.90
6	1.70	6.054E+03	1.363E+04	4.839E+05	35.51	100.07
7	1.17	5.536E+03	1.436E+04	4.428E+05	30.83	99.84
8	1.17	5.589E+03	1.431E+04	4.421E+05	30.90	99.86
9	1.70	6.064E+03	1.368E+04	4.843E+05	35.40	99.95
10	2.23	6.417E+03	1.356E+04	5.165E+05	38.08	100.20
11	2.76	6.595E+03	1.318E+04	5.311E+05	40.29	100.11
12	3.30	6.801E+03	1.321E+04	5.481E+05	41.51	100.09
13	3.83	6.997E+03	1.334E+04	5.617E+05	42.12	100.03
14	4.36	7.060E+03	1.310E+04	5.667E+05	43.24	100.05

Least-squares line for q = a*delta-T^b
a = 3.3114E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file SS12SA

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPALL
Data taken by : MEYER
This analysis done on file : SS1A
This analysis includes end-fin effect
Thermal conductivity = 14.3 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 13.88 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 2.5000
Using HEATEX insert inside tube
Tube Enhancement : RECTANGULAR FINNED TUBE
Tube material : STAINLESS-STEEL
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4137
Alpha (based on Nusselt (Tdel)) = 0.9692
Enhancement (q) = 1.131
Enhancement (Del-T) = 1.140

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	6.738E+03	1.264E+04	5.296E+05	41.89	99.74
2	3.82	6.627E+03	1.272E+04	5.209E+05	40.97	100.10
3	3.29	6.546E+03	1.304E+04	5.138E+05	39.39	100.11
4	2.75	6.344E+03	1.309E+04	4.956E+05	37.86	100.03
5	2.22	6.110E+03	1.331E+04	4.749E+05	35.69	100.03
6	1.69	5.771E+03	1.362E+04	4.475E+05	32.86	100.18
7	1.16	5.275E+03	1.436E+04	4.046E+05	28.19	99.95
8	1.16	5.282E+03	1.442E+04	4.053E+05	28.12	99.97
9	1.69	5.828E+03	1.393E+04	4.514E+05	32.40	100.15
10	2.22	6.122E+03	1.335E+04	4.746E+05	35.54	100.01
11	2.75	6.373E+03	1.319E+04	4.962E+05	37.63	100.25
12	3.23	6.511E+03	1.287E+04	5.056E+05	39.28	99.37
13	3.31	6.670E+03	1.282E+04	5.144E+05	40.11	99.80
14	4.34	6.770E+03	1.263E+04	5.229E+05	41.19	99.90

Least-squares line for q = a*delta-T^b
a = 3.2572E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file SS1A

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPALL
      Data taken by              : MEYER
      This analysis done on file : SSSA
      This analysis includes end-fin effect
      Thermal conductivity      =  14.3 (W/m.K)
      Inside diameter, Di       = 12.70 (mm)
      Outside diameter, Do      = 13.88 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 2.5000
      Using HEATEX insert inside tube
      Tube Enhancement    : RECTANGULAR FINNED TUBE
      Tube material       : STAINLESS-STEEL
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.7035
Alpha (based on Nusselt (Tdel)) =  1.1518
Enhancement (q)                  =  1.500
Enhancement (Del-T)              =  1.355
```

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.35	7.523E+03	1.510E+04	5.383E+05	39.63	99.83
2	3.82	7.432E+03	1.532E+04	5.868E+05	38.31	99.94
3	3.29	7.302E+03	1.558E+04	5.759E+05	36.96	99.84
4	2.76	7.182E+03	1.617E+04	5.658E+05	34.99	100.00
5	2.23	6.815E+03	1.596E+04	5.352E+05	33.55	99.85
6	1.70	6.451E+03	1.647E+04	5.064E+05	30.74	100.07
7	1.17	5.906E+03	1.756E+04	4.595E+05	26.17	100.08
8	1.17	5.910E+03	1.791E+04	4.600E+05	26.12	100.06
9	1.70	6.470E+03	1.659E+04	5.064E+05	30.52	99.86
10	2.23	6.874E+03	1.629E+04	5.400E+05	33.14	99.75
11	2.76	7.169E+03	1.613E+04	5.659E+05	35.09	99.89
12	3.29	7.330E+03	1.572E+04	5.804E+05	36.93	100.05
13	3.82	7.529E+03	1.573E+04	5.951E+05	37.83	100.09
14	4.35	7.677E+03	1.569E+04	6.072E+05	38.70	100.16

```
Least-squares line for q = a*delta-T^b
  a =  3.8902E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file SSSA

NOTE: 14 X-Y pairs were stored in data file
```

APPENDIX E. - UNCERTAINTY ANALYSIS

When taking experimental measurements, error is always introduced. Though great care was used to ensure the accuracy of the data taken, there is no such thing as perfectly exact measurements. While the error introduced by any one particular measurement may be small, the cumulative error introduced by all the measurements may become quite large.

Uncertainty is defined as the estimated difference between the actual measured value, and the calculated one. Kline and McClintock [Ref. 12] developed a method to determine the uncertainty of an experimentally derived value. This value V, which is a function of many measured quantities ie, V = $V(x_1,x_2,x_3,\ldots x_n)$, has an uncertainty given by the formula:

$$U_V=\left[\left[\frac{\partial V}{\partial x_1}U_1\right]^2+\left[\frac{\partial V}{\partial x_2}U_2\right]^2+\left[\frac{\partial V}{\partial x_3}U_3\right]^2+\ldots+\left[\frac{\partial V}{\partial x_n}U_n\right]^2\right]^{1/2} \qquad (30)$$

where:

U_V = the uncertainty in the dependant variable

$x_1,x_2,\ldots x_n$ = the measured independent variables

$U_1,U_2,\ldots U_n$, = measured variable uncertainty

Georgiadis [Ref. 13], gives a complete description of the uncertainty analysis used.

The uncertainty analysis program used is given in this Appendix along with examples, and was a revision of Cobb's [Ref. 8].

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU15		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.558	(Deg C)
Water Flow Rate (%)	=	60.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	3.9032E+05	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petkhov-Popov constant	=	2.7667	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.11
Heat Flux, q	1.17
Log-Mean-Tem Diff, LMTD	.72
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.37
Water-Side H.T.C., Hi	.97
Vapor-Side H.T.C., Ho	5.02

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU125R	
Pressure Condition:	Vacuum	
Vapor Temperature	= 48.719	(Deg C)
Water Flow Rate (%)	= 80.00	
Water Velocity	= 4.36	(m/s)
Heat Flux	= 3.3532E+05	(W/m^2)
Tube-metal thermal conduc.	= 390.8	(W/m.K)
Petukhov-Popov constant	= 2.8750	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.09
Heat Flux, q	1.16
Log-Mean-Tem Diff, LMTD	.71
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.36
Water-Side H.T.C., Hi	.35
Vapor-Side H.T.C., Ho	8.00

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU75		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.577	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	3.700E+05	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petknov-Popov constant	=	2.4872	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, q	1.13
Log-Mean-Tem Diff, LMTD	.76
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.41
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	6.18

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU5		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.570	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	3.330E+05	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petkhov-Popov constant	=	2.3144	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, q	1.24
Log-Mean-Tem Diff, LMTD	.83
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.49
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	5.10

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: CUSMT
Pressure Condition: Vacuum
Vapor Temperature = 43.372 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.37 (m/s)
Heat Flux = 2.5208E+05 (W/m^2)
Tube-metal thermal conduc. = 380.8 (W/m.K)
Petukhov-Popov constant = 2.3880

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, Q	1.45
Log-Mean-Tem Diff, LMTD	1.12
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.83
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	3.75

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU15A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.202	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.31	(m/s)
Heat Flux	=	1.334E+06	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petknov-Popov constant	=	3.1973	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.18
Heat Flux, q	.95
Log-Mean-Tem Diff, LMTD	.21
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	.98
Water-Side H.T.C., Hi	1.03
Vapor-Side H.T.C., Ho	17.36

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU125A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.044	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.33	(m/s)
Heat Flux	=	1.257E+06	(W/m^2)
Tube-metal thermal conduc.	=	330.8	(W/m.K)
Petkhov-Popov constant	=	3.2004	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.14
Heat Flux, q	.95
Log-Mean-Tem Diff, LMTD	.22
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	.98
Water-Side H.T.C., Hi	.99
Vapor-Side H.T.C., Ho	15.82

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CU75A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.795	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	1.175E+06	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petkhov-Popov constant	=	2.9237	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, Q	.95
Log-Mean-Tem Diff, LMTD	.24
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	.98
Water-Side H.T.C., Hi	.98
Vapor-Side H.T.C., Ho	12.75

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CUSA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.106	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	1.142E+06	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petukhov-Popov constant	=	2.7183	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.13
Heat Flux, q	.96
Log-Mean-Tem Diff, LMTD	.24
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	.99
Water-Side H.T.C., Hi	.99
Vapor-Side H.T.C., Ho	10.83

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CUSMTA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.079	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.35	(m/s)
Heat Flux	=	5.4682E+05	(W/m^2)
Tube-metal thermal conduc.	=	390.8	(W/m.K)
Petkhov-Popov constant	=	2.4435	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.10
Heat Flux, q	1.02
Log-Mean-Tem Diff, LMTD	.43
Wall Resistance, Rw	4.24
Overall H.T.C., Uo	1.11
Water-Side H.T.C., Hi	.96
Vapor-Side H.T.C., Ho	2.36

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL15		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.813	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	3.9362E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petkhov-Popov constant	=	2.3971	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.03
Heat Flux, q	1.17
Log-Mean-Tem Diff, LMTD	.72
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.38
Water-Side H.T.C., Hi	.95
Vapor-Side H.T.C., Ho	3.75

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL12S		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.575	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	3.661E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petkhov-Popov constant	=	2.4124	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, q	1.20
Log-Mean-Tem Diff, LMTD	.78
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.43
Water-Side H.T.C., Hi	.35
Vapor-Side H.T.C., Ho	6.47

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL1		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.832	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	3.433E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Patknov-Popov constant	=	2.5588	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.11
Heat Flux, q	1.23
Log-Mean-Tem Diff, LMTD	.81
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.47
Water-Side H.T.C., Hi	.37
Vapor-Side H.T.C., Ho	7.36

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL75		
Pressure Condition:	Vacuum		
Vapor Temperature	=	43.600	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	3.302E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.6	(W/m.K)
Petknov-Popov constant	=	2.5685	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.88
Reynolds Number, Re	1.08
Heat Flux, q	1.21
Log-Mean-Tem Diff, LMTD	.79
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.45
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	6.17

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	ALS		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.362	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	3.028E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petkhov-Popov constant	=	2.7317	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.08
Heat Flux, q	1.32
Log-Mean-Tem Diff, LMTD	.34
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.62
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	4.37

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	ALSMT		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.733	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	2.513E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.3	(W/m.K)
Petukhov-Popov constant	=	2.3380	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, Q	1.46
Log-Mean-Tem Diff, LMTD	1.13
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.84
Water-Side H.T.C., Hi	.94
Vapor-Side H.T.C., Ho	3.88

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	ALISA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.302	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.33	(m/s)
Heat Flux	=	1.135E+06	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petknov-Popov constant	=	2.6387	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.15
Heat Flux, q	.86
Log-Mean-Tem Diff, LMTD	.25
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	.89
Water-Side H.T.C., Hi	1.00
Vapor-Side H.T.C., Ho	12.04

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: AL125A
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature = 100.174 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.34 (m/s)
Heat Flux = 1.049E+06 (W/m^2)
Tube-metal thermal conduc. = 231.8 (W/m.K)
Petukhov-Popov constant = 2.5297

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, Q	.36
Log-Mean-Tem Diff, LMTD	.27
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.00
Water-Side H.T.C., Hi	.38
Vapor-Side H.T.C., Ho	6.76

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL1A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.033	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.31	(m/s)
Heat Flux	=	1.000E+06	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petukhov-Popov constant	=	2.7035	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.18
Heat Flux, q	.97
Log-Mean-Tem Diff, LMTD	.26
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.00
Water-Side H.T.C., Hi	1.03
Vapor-Side H.T.C., Ho	3.46

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	AL75A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.007	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	3.317E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petukhov-Popov constant	=	2.8750	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	.87
Log-Mean-Tem Diff, LMTD	.29
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.01
Water-Side H.T.C., Hi	.98
Vapor-Side H.T.C., Ho	5.22

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	ALSA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.178	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.35	(m/s)
Heat Flux	=	7.749E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Petukhov-Popov constant	=	2.3440	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.10
Heat Flux, q	.89
Log-Mean-Tem Diff, LMTD	.37
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.06
Water-Side H.T.C., Hi	.36
Vapor-Side H.T.C., Ho	2.97

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN1S		
Pressure Condition:	Vacuum		
Vapor Temperature	=	43.363	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	2.334E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petukhov-Popov constant	=	2.4413	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, Q	1.34
Log-Mean-Tem Diff, LMTD	.97
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.65
Water-Side H.T.C., Hi	.35
Vapor-Side H.T.C., Ho	6.02

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	ALSMTA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.885	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.35	(m/s)
Heat Flux	=	6.1866E+05	(W/m^2)
Tube-metal thermal conduc.	=	231.8	(W/m.K)
Patknov-Popov constant	=	2.3761	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.10
Heat Flux, q	1.03
Log-Mean-Tem Diff, LMTD	.46
Wall Resistance, Rw	5.35
Overall H.T.C., Uo	1.13
Water-Side H.T.C., Hi	.96
Vapor-Side H.T.C., Ho	2.32

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN1A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.161	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.33	(m/s)
Heat Flux	=	9.367E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petukhov-Popov constant	=	2.8633	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.13
Heat Flux, q	.38
Log-Mean-Tem Diff, LMTD	.33
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.04
Water-Side H.T.C., Hi	.39
Vapor-Side H.T.C., Ho	5.80

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN1		
Pressure Condition:	Vacuum		
Vapor Temperature	=	43.635	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	2.798E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petkhov-Popov constant	=	2.6782	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.09
Heat Flux, q	1.36
Log-Mean-Tem Diff, LMTD	1.00
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.69
Water-Side H.T.C., Hi	.95
Vapor-Side H.T.C., Ho	6.04

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN75R		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.793	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	2.823E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petukhov-Popov constant	=	2.7136	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.08
Heat Flux, q	1.35
Log-Mean-Tem Diff, LMTD	.99
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.68
Water-Side H.T.C., Hi	.94
Vapor-Side H.T.C., Ho	5.62

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CNS		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.822	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	2.643E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petkhov-Popov constant	=	2.7548	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.87
Heat Flux, q	1.41
Log-Mean-Tem Diff, LMTD	1.06
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.76
Water-Side H.T.C., Hi	.94
Vapor-Side H.T.C., Ho	4.37

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN1SA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.223	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	8.511E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petkhov-Popov constant	=	3.1874	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.13
Heat Flux, q	.87
Log-Mean-Tem Diff, LMTD	.29
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.01
Water-Side H.T.C., Hi	.98
Vapor-Side H.T.C., Ho	10.81

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CN7SAR		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.804	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.34	(m/s)
Heat Flux	=	7.996E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petukhov-Popov constant	=	2.3431	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	.33
Log-Mean-Tem Diff, LMTD	.35
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.05
Water-Side H.T.C., Hi	.37
Vapor-Side H.T.C., Ho	4.30

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	CNSA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.740	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	7.522E+05	(W/m^2)
Tube-metal thermal conduc.	=	55.3	(W/m.K)
Petkhov-Popov constant	=	2.3430	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.10
Heat Flux, q	.99
Log-Mean-Tem Diff, LMTD	.37
Wall Resistance, Rw	3.78
Overall H.T.C., Uo	1.06
Water-Side H.T.C., Hi	.36
Vapor-Side H.T.C., Ho	4.06

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SS15		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.381	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	1.730E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	1.3481	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.07
Heat Flux, q	1.87
Log-Mean-Tem Diff, LMTD	1.63
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	2.48
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	6.83

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SS1		
Pressure Condition:	Vacuum		
Vapor Temperature	=	43.738	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	1.6516E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Patkhov-Popov constant	=	2.1332	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.03
Heat Flux, Q	1.33
Log-Mean-Tem Diff, LMTD	1.70
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	2.57
Water-Side H.T.C., Hi	.35
Vapor-Side H.T.C., Ho	7.13

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: SS75
Pressure Condition: Vacuum
Vapor Temperature = 43.607 (Deg C)
Water Flow Rate (%) = 30.00
Water Velocity = 4.37 (m/s)
Heat Flux = 1.332E+05 (W/m^2)
Tube-metal thermal conduc. = 14.3 (W/m.K)
Petknov-Popov constant = 2.5816

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.07
Heat Flux, Q	1.72
Log-Mean-Tem Diff, LMTD	1.46
Wall Resistance, Rw	5.37
Overall H.T.C., Uo	2.25
Water-Side H.T.C., Hi	.34
Vapor-Side H.T.C., Ho	8.34

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	535		
Pressure Condition:	Vacuum		
Vapor Temperature	=	48.535	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.37	(m/s)
Heat Flux	=	2.0042E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	2.3353	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.07
Heat Flux, q	1.68
Log-Mean-Tem Diff, LMTD	1.40
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	2.13
Water-Side H.T.C., Hi	.94
Vapor-Side H.T.C., Ho	8.38

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SS1SA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.127	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	5.1568E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	2.4846	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.03
Heat Flux, Q	1.07
Log-Mean-Tem Diff, LMTD	.54
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	1.20
Water-Side H.T.C., Hi	.35
Vapor-Side H.T.C., Ho	5.41

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SS125A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.052	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.36	(m/s)
Heat Flux	=	5.516E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	2.8836	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.03
Heat Flux, q	1.05
Log-Mean-Tem Diff, LMTD	.51
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	1.17
Water-Side H.T.C., Hi	.95
Vapor-Side H.T.C., Ho	7.82

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: SS1A
Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature = 39.300 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.34 (m/s)
Heat Flux = 5.080E+05 (W/m^2)
Tube-metal thermal conduc. = 14.3 (W/m.K)
Petukhov-Popov constant = 2.4137

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.30
Reynolds Number, Re	1.12
Heat Flux, q	1.08
Log-Mean-Tem Diff, LMTD	.55
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	1.21
Water-Side H.T.C., Hi	.38
Vapor-Side H.T.C., Ho	6.64

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SS75A		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	99.868	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.35	(m/s)
Heat Flux	=	6.161E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	3.0659	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.11
Heat Flux, q	1.03
Log-Mean-Tem Diff, LMTD	.45
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	1.12
Water-Side H.T.C., Hi	.97
Vapor-Side H.T.C., Ho	13.11

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name:	SSSA		
Pressure Condition:	Atmospheric (101 kPa)		
Vapor Temperature	=	100.151	(Deg C)
Water Flow Rate (%)	=	80.00	
Water Velocity	=	4.35	(m/s)
Heat Flux	=	5.3222E+05	(W/m^2)
Tube-metal thermal conduc.	=	14.3	(W/m.K)
Petkhov-Popov constant	=	2.7035	

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.11
Heat Flux, q	1.04
Log-Mean-Tem Diff, LMTD	.47
Wall Resistance, Rw	5.87
Overall H.T.C., Uo	1.14
Water-Side H.T.C., Hi	.97
Vapor-Side H.T.C., Ho	10.56

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